LUME 4

FINAL REPORT
OF THE
SPACE SHUTTLE
PAYLOAD PLANNING WORKING GROUPS

LIFE SCIENCES

MAY 1973

NATIONAL AERONAUTICS & SPACE ADMINISTRATION
GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND 20771

GLOSSARY

Abbreviation	Description
ATM	Apollo Telescope Mount
COS	Cosmic Ray Satellite
CORSA	Japanese X-Ray Satellite
EVA	Extra Vehicular Activity
ERS	Earth Resources Satellite
EGRET	Energetic Gamma Ray Experiment
ESRO	European Space Research Organization
EMI	Electromagnetic Interference
HEAO	High Energy Astronomy Observation Satellite
IMP	Interplanetary Monitoring Platform
MSFC	Marshall Space Flight Center
OSO	Orbiting Solar Observatory
PI	Principal Investigator
SAS	Small Astronomy Satellite
SR&T	Supporting Research and Technology
STP	Standard Temperature & Pressure
TD	Thor-Delta (European Space Research Satellite)
TASC	Total Absorption Shower Counter
TTL	Transistor-Transistor Logic
UK	United Kingdom
XUV	Extreme Ultraviolet
HELIOS	German/US Cooperative Solar Probe

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FOREWORD*

In January 1972 the United States decided to develop a new space transportation system, based on a reusable space shuttle, to replace the present expendable system.

By January 1973 planning had progressed to the point that through the European Space Research Organization (ESRO) several European nations decided to develop a Space Laboratory consisting of a manned laboratory and a pallet for remotely operated experiments to be used with the shuttle transportation system when it becomes operational in 1980.

In order to better understand the requirements which the space transportation must meet in the 80's and beyond; to provide guidance for the design and development of the shuttle and the spacelab; and most importantly, to plan a space science and applications program for the 80's to exploit the potential of the shuttle and the spacelab, the United States and Europe have actively begun to plan their space programs for the period 1978-1985, the period of transition from the expendable system to the reusable system. This includes planning for all possible modes of shuttle utilization including launching automated spacecraft, servicing spacecraft, and serving as a base for observations. The latter is referred to as the sortie mode. The first step in sortie mode planning was the Space Shuttle Sortie Workshop for NASA scientists and technologists held at the Goddard Space Flight Center during the week of July 31 to August 4, 1972. For the purposes of that workshop, shuttle sortie missions were defined as including those shuttle missions which employ observations or operations (1) from the shuttle itself, (2) with subsatellites of the shuttle, or (3) with shuttle deployed automated spacecraft having unattended lifetimes of less than about half a year.

In general the workshop was directed towards the education of selected scientific and technical personnel within NASA on the basic capabilities of the shuttle sortie mode and the further definition of how the sortie mode of operation could benefit particular disciplines. The specific workshop objectives included:

- Informing potential NASA users of the present sortie mode characteristics and capabilities
- Informing shuttle developers of user desires and requirements
- An initial assessment of the potential role of the sortie mode in each of the several NASA discipline programs
- The identification of specific sortie missions with their characteristics and requirements

*Reprinted from the volume entitled "Executive Summaries".

- The identification of the policies and procedures which must be changed or instituted to fully exploit the potential of the sortie mode
- Determining the next series of steps required to plan and implement sortie mode missions.

To accomplish these objectives 15 discipline working groups were established. The individual groups covered essentially all the space sciences, applications, technologies, and life sciences. In order to encourage dialogue between the users and the developers attendance was limited to about 200 individuals. The proceedings were, however, promptly published and widely distributed. From these proceedings it is apparent that the workshop met its specific objectives. It also generated a spirit of cooperation and enthusiasm among the participants.

The next step was to broaden the membership of the working groups to include non-NASA users and to consider all modes of use of the shuttle. To implement both objectives the working group memberships were expanded in the fall of 1972. At this time some of the working groups were combined where there was appreciable overlap. This resulted in the establishment of the 10 discipline working groups given in Attachment A. In addition European scientists and official representatives of ESRO were added to the working groups. The specific objectives of these working groups were to:

- Review the findings of the GSFC workshop with the working groups
- Identify as far as possible the missions (by mode) that will be required to meet the discipline objectives for the period 1978 to 1985
- Identify any new requirements or any modifications to the requirements in the GSFC report for the shuttle and sortie systems
- Identify the systems and subsystems that must be developed to meet the discipline objectives and indicate their priority and/or the sequence in which they should be developed
- Identify any new supporting research and technology activity which needs to be initiated
- Identify any changes in existing procedures or any new policies or procedures which are required in order to exploit the full potential of the shuttle for science, exploration and applications, and provide the easiest and widest possible involvement of competent scientists in space science
- Prepare cost estimates, development schedules and priority ranking for initial two or three missions

In order to keep this planning activity in phase with the shuttle system planning the initial reports from these groups were scheduled to be made available by the spring of 1973. It was also felt necessary that the individual working group activities be coordinated both between the groups and with the shuttle system planning. As a result, the steering group given in Attachment B was established.

Early in 1973, NASA and the National Academy of Sciences jointly decided that it would be appropriate for a special summer study to review the plans for shuttle utilization in the science disciplines. This summer study has now been scheduled for July 1973. It is anticipated that the results of the working group activities to date will form a significant input into this study.

In the following sections of the summary document are the executive summaries of each of the working group reports. While these give a general picture of the shuttle utilization plan, the specific plan in each discipline area can best be obtained from the full report of that working group. Each working group report has been printed as a separate volume in this publication so that individuals can select those in which they are particularly interested.

From these working group reports it is apparent that an appreciable effort has been made to exploit the full capability of the shuttle. It is, however, also apparent that much work remains to be done. To accomplish this important work, the discipline working groups will continue.

Finally it is evident from these reports that many individuals and groups have devoted appreciable effort to this important planning activity. I would like to express my appreciation for this effort and stress the importance of such activities if we are to realize the full potential of space systems in the 1980s.

John E. Naugle

John E. Naugle, Chairman
NASA Shuttle Payload Planning
Steering Group

ATTACHMENT A

LIST OF WORKING GROUPS

	GROUP NAME	CHAIRMAN	CO-CHAIRMAN
1.	ASTRONOMY	Dr. N. Roman (HQ)	Dr. D. S. Leckrone (GSFC)
2.	ATMOSPHERIC & SPACE PHYSICS	Dr. E. Schmerling (HQ)	Mr. W. Roberts (MSFC)
3.	HIGH ENERGY ASTROPHYSICS	Dr. A. Opp (HQ)	Dr. F. McDonald (GSFC)
4.	LIFE SCIENCES	Dr. R. Hessberg (HQ)	Dr. D. Winter (ARC)
5.	SOLAR PHYSICS	Dr. G. Oertel (HQ)	Mr. K. Frost (GSFC)
6.	COMMUNICATIONS & NAVIGATION	Mr. E. Ehrlich (HQ)	Mr. C. Quantock (MSFC)
7.	EARTH OBSERVATIONS	Dr. M. Tepper (HQ)	Dr. W. O. Davis (DoC/NOAA)
8.	EARTH AND OCEAN PHYSICS	Mr. B. Milwitzky (HQ)	Dr. F. Vonbun (GSFC)
9.	MATERIALS PROCESSING AND SPACE MANUFACTURING	Dr. J. Bredt (HQ)	Dr. B. Montgomery (MSFC)
10.	SPACE TECHNOLOGY	Mr. D. Novik (HQ)	Mr. R. Hook (LaRC)

NASA AD HOC ORGANIZATION FOR SHUTTLE PAYLOAD PLANNING

POLICY GROUP

H. Newell—Chairman
D. Myers
C. Mathews
J. Naugle
C. Berry
A. Frutkin

STEERING GROUP

J. Naugle — Chairman
R. Johnson — Exec. Secretary
L. Meredith
J. Mitchell
S. White
L. Jaffe
P. Culbertson
S. Himmel
H. Ortner (ESRO)

SCIENCE WORKING GROUPS

COORD./Mitchell

ASTRONOMY/Roman
SOLAR PHYSICS/Oertel
HIGH-ENERGY ASTROPHYSICS/Opp
ATMOSPHERIC & SPACE PHYSICS/Schmerling

APPLICATIONS WORKING GROUPS

COORD./Jaffe

COMM. & NAV./Ehrlich
EARTH & OCEAN PHYSICS/ Milwitzky
EARTH OBSERVATIONS/ Tepper
MATERIAL SCIENCE & SPACE PROCESSING/Bredt

LIFE SCIENCE WORKING GROUP

COORD./White

LIFE SCIENCE/Hessberg

SPACE TECHNOLOGY WORKING GROUP

COORD./Hayes

SPACE TECHNOLOGY/ Novik

ATTACHMENT B

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LIFE SCIENCES WORKING GROUP

EXECUTIVE SUMMARY

INTRODUCTION

The Life Sciences Discipline is an aggregate of related research and technology including planetary biology, biomedicine, biology and advanced technology. The planning in the Life Sciences is predicated on a basic criterion that proposed areas of investigation have a space specific justification, namely, that the mechanism involved in a proposed experimental model has a gravity dependent function or there is a unique aspect to the space flight environment which precludes evaluating or testing completely the experimental hypothesis in ground-based research. The plan is a valuable overview of the scope of the Life Sciences potential payload planning developed in sufficient detail to permit subsequent programming which involves definitive engineering, hardware requirements, schedules and costs.

OBJECTIVES

Continue the research directed at understanding the origin of life and the search for extraterrestrial evidence or precursors of life.

Continue the biomedical research necessary to understand mechanisms and provide the criteria for countermeasures in support of manned space flight.

Continue advanced technology development on life support, protective systems and work aids to provide as near an Earth atmospheric environment for man as possible — to provide him with protection from hazards of the space environment, optimize his ability to work in space and to maintain his health.

Continue the research in biology to investigate those mechanisms observed to have changed in space on man-models wherein the investigation cannot be done on man and to study basic biological functions at all levels or organization (subcellular, cellular, system and organism) influenced by gravity, radiation and circadian rhythms; factors which are inherent in the space flight environment.

MISSIONS

Although the Life Sciences Payload Planning Group identified as highly desirable an early requirement for a 30 day capability, the plan encompasses the total

Shuttle capability of early carry-on payloads, pallet payloads and subsequently the 30 day dedicated Life Sciences Lab which will be used selectively for 7 day missions until 30 day missions are available. The following two tables display a matrix of flight opportunities by category of Life Sciences research or technology and do not reflect individual experiments.

Table 1

Payloads

Carry-On Payloads	1979	1980	1981	1982
Life Support Systems	2	2	2	
Biology (Advanced Biopack)	2	2	2	2
Medical	2	2		
Man System Integration	2	2		
Pallet Payload				
Life Sciences Research	1 launched & retrieved			
Module	1 retrieved			
Free Flying teleoperators	3	1	2	

CONSIDERATIONS

The Life Sciences represents a broad, multidisciplinary scientific population including bioengineers, biophysicists, biologists, physicians, psychologists, physiologists, radiobiologists, etc. The experiment planning interfaces with other disciplines in that Life Sciences can capitalize on the EVA planned by other groups, can obtain human performance data from many of the other manned experiments and can evaluate man-machine integration factors with almost every payload mission, including teleoperations.

The Life Sciences planning incorporates carry-on payloads in the early Shuttle flight era, uses the pallet mode for the Life Sciences Module, uses appropriate elements of the 30 day dedicated lab or 7 day missions and strongly supports an early 30 day Shuttle capability.

Table 2

Proposed Total Flight Schedule

SORTIE LAB 7/30 Days	79	80	81	82	83	84	85	86	87	88	89
BIOLOGY	4X	4X	4X	4X	4X	4X	4X	4X	4X	4X	4X
*PLANETARY BIOLOGY											
Planetary	XX	4X	XX	4X	4X	XXX	4X	XX	4X	XX	4X
BIOMEDICINE											
Models	XX	4X	4X	XXX	XX	XX	XX	XX	X	X	X
Man	15X	24X	32X	40X	60X	60X	60X	60X	60X	60X	60X
ADVANCED TECHNOLOGY											
LSS/Protective Devices	XXX	XXX	XXX	XX	XX	X	X	X	X	X	X
Teleoperators	X	X	X	X	X	X	X	X	X	X	X
EVA	XX	XX	XX	X	X	X	X	X	X	X	X

*The original Table 8-2 has been changed to delete the Earth Orbital line under PLANETARY BIOLOGY since further study of this area has indicated there are no Life Sciences requirements for Earth Orbital experiments in PLANETARY BIOLOGY.

NOTE: The above table represents the number of flight opportunities that could be used by the discipline areas listed and not the number of experiments.

The plan identifies an inseparable interaction with the Orbiter. The food, water and waste management system is baselined in the Orbiter. Any medical experiment which would require measurement of food and fluid intake, output and sampling reacts with this subsystem of the Orbiter.

The introduction of the scientist/passenger population creates a requirement for validation of the medical standards and criteria used to select this new space flight population which is reflected in Table 2, BIOMEDICINE, Man.

The need for an on-board centrifuge to provide a 1-G control for biological experiments has been proposed. The rationale for this requirement, which has proponents and opponents, needs to be reviewed in-depth and a scientific position, pro or con, established due to the engineering complexity of incorporating a centrifuge.

SUMMARY

The Life Sciences Shuttle Payload Planning Group has developed a thorough representation of the payload areas which reflect a logical and cohesive organization of the diverse disciplines represented by Life Sciences. This plan, as any planning document should, offers an excess of candidate payloads from which orderly and selective programming can be implemented. It is anticipated that in order to serve a useful purpose, the plan will be augmented and/or modified as additional payload planning activities are completed.

REPORT OF THE LIFE SCIENCES WORKING GROUP

INTRODUCTION

The first meeting of the Life Sciences Shuttle Payload Planning Working Group took place at Goddard Space Flight Center on August 1 - 2, 1972.

The Working Group consisted of the following:

R. Hessberg, Hq, Chairman	H. Sandler, ARC
D. Winter, ARC, Co-Chairman	T. Taketa, ARC
J. Hilchey, MSFC	M. Sadoff, ARC
W. Hull, JSC	P. Quattrone, ARC
J. Mason, JSC	R. Young, Hq
	R. Dunning, Hq

A second meeting was held at Headquarters NASA from November 8 through 10, 1972. Dr. Berry welcomed the group and expressed his interest in support of the activities to be undertaken and re-emphasized the importance of this early effort in planning for Life Sciences payloads for the Shuttle era. Meeting with the panel members were the following individuals who represented expertise in the scientific disciplines indicated:

Dr. Robert Krauss	- Biology
Professor Patricia Lindop, ESRO	- Radiobiology
Dr. Thomas Malone	- Teleoperations
Dr. Jerry Mayeux	- Microbiology
Dr. Jesse Orlansky	- Behavioral Sciences
Dr. Jack Spurlock	- Life Support Systems

Also participating in the second meeting were:

Dr. Stanley White, Hq NASA
Miss Ann Wagoner, National Academy of Sciences

A new dimension evolved during the meetings which has promulgated a fascinating concept of cross-discipline experiment interest and interface. There is a very fundamental problem associated with the research and development efforts in the reverse osmosis technology approach currently being developed for longer duration life support systems. The problem involves transport functions at a fluid/membrane interface. (This is covered in more detail in Appendix D). It is well established that the solute gradient at the membrane interface is gravity dependent. If the problem is related to free convection on the membrane surface which may set up polarization, we are talking to a question to be answered in cellular physiology: namely, what is the effect on convection in a living cell or cells and its effect on fluid transport across the cell membrane? Both of these experimental areas are described later in Appendices A and D, but deserve mention here as examples of disciplinary interfaces which will mutually enhance the needed understanding of this physical/chemical/physiological factor of fundamental importance in Life Sciences systems functions.

A requirement evolved which identified the need to acquire human performance data from other than the specifically dedicated Life Sciences experiments. A mechanism, whereby human activities in other payload area and experiments can be reviewed with their data recording format, needs to be established. The method of selection and approval of appropriate experiments for supporting the human performance area must be established. The current timeline planning problem plaguing Skylab is sufficient evidence of how little we know of how long it takes, compared to one "g" for man to perform a given function in the space flight environment. The earlier this is done in the Shuttle Program, the more reliable will be the planning and training for longer missions. Inherent in this approach is the collecting of selected physiological data concurrently with the performance data.

A valid concern was raised which will require further evaluation. If we are to pursue the "off the shelf" hardware cost effective concept, it could impair science quality since some of the analytical instruments required for Life Sciences research data acquisition currently available may not operate satisfactorily after exposure to the acceleration and vibration of Shuttle launch. When, by whom, and with what funds will the review design, development and fabrication of the required instrumentation be accomplished?

The reader of this material must keep in mind that this report is a planning document in response to the requirement to provide insight into the scope of the Life Sciences areas of interest. This material has been developed in enough detail to provide for the follow-on efforts which will define the associated engineering and hardware requirements for a more definitive program, scheduling and costing details. Underlying the entire planning represented by the Appendices to these two reports has been a basic criterion that all proposed areas of investigation should have a space specific justification: namely, that the mechanism involved in the proposed experimental model should have a gravity dependent function or there is a unique aspect to the space flight environment which precludes evaluating or testing completely the experimental hypothesis in ground-based research.

As Chairman, I would be remiss if I did not acknowledge the highly productive efforts of this group as represented by this report of the Life Sciences Shuttle Payload Planning in all of the areas. Their genuine interest, unselfish contribution of their time, breadth of scientific and technical knowledge and willingness to participate cannot be overstated. I am indeed grateful to them and feel the international Life Sciences community as well as NASA will benefit by this Life Sciences section of the Shuttle Sortie Payload Planning.

In reviewing this report, the reader must keep in mind that Tables 1 and 2 display a matrix of flight opportunities by category of life science research or technology and do not represent experiments.

Table 1

Payloads

CARRY-ON PAYLOADS	1979	1980	1981	1982
Life Support Systems	2	2	2	
Biology (Advanced Biopack)	2	2	2	2
Medical	2	2		
Man System Integration	2	2		
PALLET PAYLOAD:				
Life Sciences Research Module (vice Bioresearch Module)	1 launched & retrieved 1 retrieved			
Free Flying teleoperators	3	1	2	

DISCIPLINE AREA—LIFE SCIENCES

The Life Sciences Discipline is an aggregate of related research and technology efforts including planetary biology, biomedicine, biology, and advanced technology. It is a continuing program from which design criteria and technology development can be obtained whenever flight programs or systems initiate their design phase.

Table 2

Proposed Total Flight Schedule

SORTIE LAB 7/30 Days	79	80	81	82	83	84	85	86	87	88	89
BIOLOGY	4X	4X	4X	4X	4X	4X	4X	4X	4X	4X	4X
PLANETARY BIOLOGY											
Planetary	XX	4X	XX	4X	4X	XXX	4X	XX	4X	XX	4X
BIOMEDICINE											
Models	XX	4X	4X	XXX	XX	XX	XX	XX	X	X	X
Man	15X	24X	32X	40X	60X	60X	60X	60X	60X	60X	60X
ADVANCED TECHNOLOGY											
LSS/Protective Devices	XXX	XXX	XXX	XX	XX	X	X	X	X	X	X
Teleoperators	X	X	X	X	X	X	X	X	X	X	X
EVA	XX	XX	XX	X	X	X	X	X	X	X	X

NOTE: The above table represents the number of flight opportunities that could be used by the discipline areas listed and not the number of experiments.

GOALS AND OBJECTIVES

1. Continue the research directed at understanding the origin of life and the search for extraterrestrial evidence or precursors of life.

2. Continue the biomedical research necessary to understand mechanisms and provide the criteria for countermeasures in support of manned space flight.

3. Continue advanced technology development on life support, protective systems, and work aids to provide as near an earth atmospheric environment for man as possible in order to provide him with protection from hazards of the space environment, optimize his ability to work in space, and to maintain his health.

4. Continue the research in biology to investigate those mechanisms observed to have changed in space on man-models wherein the investigation cannot be done on man, and to study basic biological functions at all levels or organization (subcellular, cellular, system, and organism) influenced by gravity, radiation, and circadian rhythms; factors which are inherent in the space flight environment.

POTENTIAL CONTRIBUTIONS

- The 7-30-day Shuttle offers Life Sciences an opportunity to explore and evaluate the essential SR&T for future earth orbital space stations, manned planetary explorations, and the search for extraterrestrial life.

- Skylab will not answer all the questions of biomedical concern, therefore, the 7-30-day Shuttle will provide the first opportunity for follow-on studies.

- The Shuttle offers the Life Sciences community the first opportunity to conduct basic biological research in a systematic fashion, capitalizing on the unique features of the space environment.

- The Shuttle offers the opportunity to explore the utility of the space environment for the solution of terrestrial biomedical problems not approachable by other means.

- The Shuttle provides a platform for the evaluation of potential Life Sciences applications in earth resources, public health ecology, the earth's ecosystems, and the delivery of medical services.

ORBITER IMPACTS

The Panel has identified important constraints that the Life Sciences payload places on the orbiter with the hope that these constraints will be considered in the design of the orbiter. These were highlighted and placed ahead of all else since the orbiter design is so close in real time.

As a result of extensive discussion, it was determined that Life Sciences experiments placed the following constraints on the Shuttle orbiter:

- A feeding system that will permit accurate determination of food and fluid intake.
- A waste management system that will measure urine volume and provide for obtaining samples.
- A waste management system that will determine the wet or dry mass of feces and the potential capability for obtaining samples.
- An environment as close to zero "g" as can be engineered into the system.
- A late access to the payload, since mnay of the Life Sciences' experiments are living systems and often need to be either placed into the payload late in the countdown or may need to be examined at a late stage.
- A satellite launch and retrieval capability.
- Many of the Life Sciences biological systems are vibration-sensitive, and a requirement exists for a detailed definition of the vibration environment in order to assess the contribution of vibration to the understanding of the biological experiment results and the role that vibration has played in the changes observed.
- The orbiter should serve as a launch platform for unmanned probes in support of planetary biology goals and objectives.
- 1 "g" control should be available inflight as the only valid method of differentiating biological changes attributable to weightlessness. Although the burden of introducing the centrifuge as an inflight 1 "g" control will fall into the Life Sciences Sortie Lab design, there could well be an impact on the Orbiter stabilization and control system due to the gyroscopic effects produced by the centrifuge. The introduction of this capability during the Carry-on and Shared payload phase of the Shuttle Program does not appear feasible at this time but should be considered during the design phase of the program.

DESIGN REQUIREMENTS

- Length of Flights—Technology, biology, and medicine support 30 days or longer beginning with 1979 or as soon thereafter as possible. Can use 7 days for Technology, Planetary Biology, Medicine, and Biology.

- Orbit—For majority of work, orbital attitude and inclination are not critical. For radiation research, polar flights or flights beyond radiation belts (free-flying satellites) are indicated.

- Data Requirements—Return of specimens, film tape and records. TM of sensor (analog and digital), audio and video; bit rates and analog bandwidths are being determined.

- Role and Number of Persons in Orbit—

1979, 80, 81 -	1 LS Mission Specialist 1 Dedicated Scientist
1982 - 88 -	1 LS Mission Specialist 3 Dedicated Scientists
1989 ---	2 LS Mission Specialists 6 Dedicated Scientists

- Power and Thermal—

  a. Carry-on Payloads

Power	Thermal
Av. 100w	TBD
Peak 500w	

  b. Shared Shuttle Sortie Lab

Power	Thermal
Av. 2.53 Kw	3.21 Kw thermal
Peak 3.17 Kw	(based on 4 men using lab).

c. Dedicated Shuttle Lab

Power	Thermal
Av. 3.92 Kw	4.60 Kw thermal
Peak 4.90 Kw	(based on 4 men using lab).

- Weight & Volume—

a. Carry-on Payloads: (2 packages/payload)

Weight	Volume
300 lbs. (150 lbs/package)	30.0 ft.^{3} (15.0 ft.^{3}/package) Dimensions examplary: 2 ft. x 3 ft. x 2.5 ft.).

b. Shared Shuttle Sortie Lab

Weight	Volume
14,200 lbs. (Including equipment, support subsystems, and "can".)	390 ft.^{3} (equipment volume only) Preliminary layout occupied a 14 ft. diameter cylinder 22 ft. long.

c. Dedicated Shuttle Lab

Weight	Volume
23,400 lbs. (Including equipment, support subsystems, and "can".)	876 ft.^{3} (equipment volume only) Preliminary layout occupied a 14 ft. diameter cylinder 36.3 ft. long.

- EVA Requirements—In Shuttle Bay for EVA Research.

- Correlative Measurements—On crewmen as available; housekeeping data, Shuttle performance data, especially g and vibration.

- General Support Requirements—With the emergence of the need for a 1 "g" experiment control, the following new requirements are described:

  Environment: The control subjects must see the same total environment as the test subjects from lift-off to splashdown. This includes parameters such as acoustic, thermal vibration, acceleration pressure, contamination, electromagnetic life support, etc. Thus, the packages should be co-located for launch and re-entry. During earth orbit, they should be configured so that they see identical cabin environments. Further the centrifuge should be designed to be vibration free.

Radius: Minimum centrifuge radius requirements are dictated by the coriolis sensitivity of the test subject. Current laboratory experience at Ames Research Center has defined the minimum for rats at 4 ft. and since each of the proposed Life Sciences Shuttle configurations provides for rat test subjects, a centrifuge is required that has at least a 4 ft. radius, but preferably longer (e.g., maximum allowable radius limited by the cylinder diameter of the lab module. We anticipate that higher or lower "g" levels can be provided for other research by utilizing inboard and outboard stations from the referenced 1 "g". Other experiments could have different radii requirements(i.e., microbiology would be satisfied with a shorter radius centrifuge) but the range of needs is still to be determined.

- Stabilization & Pointing—Requirements for antenna pointing for earth tracking; camera pointing for earth scanning.

  $\leq 10^{-5}$ g for biology experiments
  10^{-3} g for medical and technology

- Special Operating Constraints—Low level "g" requirements.

  The short term gravitational forces introduced during rotation of the spacecraft may be sufficient to negate some of the experiments in gravitational biology or on synergestic effects of space environments. It is recommended that the Life Sciences Sortie Lab missions be structured so that no rotation of the Lab or Shuttle is required once the experiments have been initiated. This may require consideration of a movable antenna or some other means to provide communication and data transmission with ground stations.

- Documentation Required—None.

- Contamination Requirements—None.

- Other—None.

DISCUSSION

- Many valid investigations of early changes in Life Sciences experiments are achievable in seven days. The five days available in a seven day mission will permit the use of microbial models or other organisms with short life cycles for the assessment of basic mechanisms at play in cell metabolism, growth, replication and kinetics. The results of short exposures to weightlessness will be used as building blocks toward the longer duration mission experiments involving growth, development, reproduction, life cycles, etc. For example, embroyonic development and egg hatching can be investigated in five days, but not uninterrupted growth, development or reproduction; yet to study the longer cyclic effects, the embryonic development and hatching phases must be investigated. It must be kept in mind that the life cycle of mice ranges from 90 to 120 days but there are other organisms with shorter life cycles in the invertebrate category and a candidate vertebrate, the quail, has a 40-60 day life cycle. This serves to illustrate that there is a step function approach that can and will be utilized in developing the Life Sciences payloads which will take advantage of every potential phase of the Shuttle Flight Schedule from Carry-on payloads to Dedicated long duration missions.

- The Life Sciences Panel has identified a need for a dedicated laboratory early in the Shuttle Sortie mode which appears to be a highly cost-effective approach by virtue of the consolidation of experiments reducing the run-out costs of flying the experiments serially.

  The Life Sciences' requirements identify a 24-foot requirement for the 30-day lab. Attempts to engineer the Life Sciences Laboratory requirements in less space will increase costs predicted on current off-the-shelf flight-qualified hardware used in integration studies over the past one and one-half years to identify dedicated Life Sciences Laboratory concepts.

- Reducing documentation Q and A requirements, and associated evaluation test and training requirements, will help achieve the low-cost goal for the Shuttle.

- The use of common laboratory equipment and the reuse of equipment will amortize much of the initial cost of Life Sciences modules and laboratories.

- Though the concept of an onboard control at 1 "g" is an excellent scientific recommendation, the design and integration of this capability will involve formidable problems both biologically and from an engineering point of view. The definition of motion of biological tissues with the device such as a centrifuge must be carefully studied to avoid introduction of forces which could mask or negate the assumed 1 "g" control requirement.

This position is substantiated by the recommendation of the AIBS contained in their December 15, 1967 Report to NASA titled, "Bioscience Research During Earth-Orbiting Mission." (See Introduction). This same requirement has recently (November 1972) been re-emphasized by the Space Medicine and Biology Committee of the Space Science Board, National Academy of Sciences.

The Working Group recommends that the National Academy of Sciences Summer Study specifically address the extremely difficult decision as to the advantages and disadvantages of introducing a centrifuge inflight as a 1 "g" control for biological and/or Life Sciences experiments. This issue has many proponents and opponents and the need for a positive position and recommendation must be established in order to design and develop the supporting hardware capability for the Shuttle Sortie mode.

MAGNITUDE OF USER COMMUNITY

It is important to keep in mind that Life Sciences encompasses many disciplines including Biology, Physiology, Microbiology, Biochemistry, Exobiology, Behavioral Sciences, Psychology, Human Engineering, Life Support Systems, Protective Devices and that it must deal with environmental control, thermal control, bioinstrumentation and associated instrumentation with cabin environment monitoring. All this makes up the potential user community, which reaches literally hundreds of thousands of scientists and engineers in universities, nonprofit research organizations, and the aerospace and allied industries.

RECOMMENDED POLICY AND PROCEDURE CHANGES

1. Currently, there is no single management policy for Life Sciences experiments in NASA, and the Panel recommends the publishing of a NASA Management Instruction (NMI) which would establish the evaluation of experiment proposals, their selection and their management through flight and post flight data analysis, publishing, and reporting.

2. The Panel feels that the Shuttle Program Office should issue an AFO at the very earliest opportunity in order to solicit interest and response

from the user community outside NASA and to permit the assembly of interested scientists to exchange essential information concerning Shuttle payload experiment activities.

3. The Panel unanimously supports the policy of PI participation from experiment inception to post flight recovery, data reduction, and reporting.

4. Any policy change which would bring the 30-day capability into the near time frame of Shuttle operations is highly desirable to fully exploit the Shuttle Sortie mode for Life Sciences.

RECOMMENDED FUTURE ACTIONS

1. Establish this panel with a possible expansion by 2 - 4 members as the single management group for the Shuttle payload planning for the Director of Life Sciences, Headquarters, NASA.

2. Have all other current and proposed Shuttle payload planning activities under the auspices of this panel.

3. Formally establish this panel and approve its request to continue meeting at the intervals necessary to effectively contribute to the goals and objectives of the Shuttle Sortie mission experiment activities.

APPENDIX A

LIFE SCIENCES/SPACE BIOLOGY

INTRODUCTION

GRAVITATIONAL BIOLOGY

All forms of life on earth have evolved under the influence of earth's gravitational field. As such, various life processes (e.g., embryogenesis, growth, development, morphogenesis, regulatory mechanisms, etc.) may be considered to be gravity dependent. While we can study the biological effects of increase in gravitational fields on earth by centrifugation, we cannot produce extended weightlessness, although in some organisms we can compensate for it; for example, by use of the horizontal clinostat.

The accessibility to space environment provides as the opportunity and means of conducting biological experimentation in the weightless environment—one to which no organism in the earth's evolutionary history has been exposed. This new dimension for biological research can be significant at three levels: the intrinsic interest in how organisms react to the unique weightless environment; the immediate application of such knowledge to the welfare of man on long-duration space missions; and the definition and clarification of the influence that gravity has exerted on the growth, development, and evolution of organism.

In considering the unifying principles that describe life as it is known on earth, biologists are convinced that we deal with a single kind of life, i.e., that all known forms of life can be traced back to a common origin. In this sense, biology has until now been a provincial science, for we have studied one type of life in one group of environments and our generalizations are based on this group of examples. Just as the planetary biologists have an opportunity to vastly increase our biological knowledge by discovery of an independently evolved life on other planets under different environment conditions, so the space biologist may increase our understanding of life on earth by studying it in the weightless environment of space and extending this newly acquired knowledge for the benefit of mankind.

An in-depth study will be conducted on a variety of biological materials ranging from cells, tissues, seeds, plants, invertebrates, and vertebrates. This approach will fulfill the needs and desires of the fundamental biolgists as well as supplement studies on man himself. Vital gaps in knowledge in human studies can be best supplied, or even exclusively supplied, by studies on lower forms of life. Man is considered to be part of a biological continuance which extends from the simplest forms of life to man.

While the 7-day Shuttle Sortie missions will suffice for studies involving cell replication, embryogenesis and other early stages of life as well as those of activity, longer duration earth orbiting flights (e.g., 30 days or more) will be required for growth, development, morphogenesis, and life cycle studies in most cases.

BIOLOGICAL RHYTHMS

Many, if not all, living organisms on earth possess rhythmicities of one kind or another. There has long been a controversy as to whether these rhythms are controlled by internal cellular processes or external environmental factors. A multitude of experiments have been designed to resolve this fundamental biological question. Unfortunately, it has been extremely difficult, if not impossible, to control all of the terrestrial environmental variables capable of influencing biological processes. The Shuttle Sortie offers us the possibility of removing certain biological systems from virtually all of these terrestrial variables. By this means, it is hoped that experiments can be designed to resolve the question of intrinsic versus extrinsic control of biological "clocks."

To derive meaningful data, eccentric earth-orbital flights of relatively long duration (e.g., 30 days or longer) are required and eventually deep space probes may be required depending upon results of eccentric earth-orbital flight experiments. A variety of well-tested, reliable, test organisms (plants, invertebrates and mammals) will be used.

RADIATION BIOLOGY

The intensities of high-energy, high Z (HZE) particles in the space environment are of sufficient magnitude to pose a possible serious hazard for the crew on long-term space missions. Experimental data are needed to assess and define the biological implications of HZE particles and the combined effects of ionizing radiation and weightlessness for developing realistic radiation exposure guidelines and for providing protective and/or preventative measures and procedures against radiation hazards for long duration manned space flights. To understand the mechanism of biological action of high-LET HZE radiations, it is necessary and important to relate their physical measurements (dosimetry) accurately and precisely to biological damage at the molecular and cellular levels. For this reason, appropriate dosimetric capability must be provided to determine the trajectory, energy, and Z number of particles impacting biological targets.

While substantial effort is being made to determine and understand the biologic effects of accelerator-produced particles and the combined effects of compensated gravity (using the horizontal clinostat) and ionizing radiation, studies in the space environment are essential because the HZE particles of concern are currently not available for ground-based investigation; neither do we have the means of simulating the weightless environment of space. A variety of appropriate biological materials (e.g., seeds, plants, invertebrates, cells in culture, mammals, etc.) will be used to investigate effects at the molecular, cellular and organism levels.

The exposure rates from HZE particles for a 270-nautical-mile, 55° inclined orbit and an earth-synchronous, 0° inclined orbit are estimated to be in the order of 0.05 and 0.1 rem per day, respectively. The maximum particle flux that can be expected at the respective earth orbital inclinations during minimum solar activity is estimated at 70 and 140 particles of $Z \geqslant 6$ per cm^2 per day, and 2-3 and 5 particles of $Z \geqslant 26$ per cm^2 per day. The estimated number of thindowns, which are of particular concern because of their intense ionization and severe damaging potential, for the respective earth orbital inclinations are 2-3 particles of $Z \geqslant 6$ and less than 1 particle of $Z \geqslant 26$ per cm^2 tissue per day.

It is anticipated from previous short duration (2-3 days) balloon flight and earth orbiting satellite experiments, that significant results can be achieved in 7-day Shuttle Sortie missions. However, longer duration earth orbiting Sortie missions (e.g., 30 days) are highly desirable at the earliest possible opportunity for both the HZE particle radiation studies and the combined effects of radiation and weightlessness. For the HZE particle studies, earth synchronous, 0° inclined orbits (North-South pole orbits) and placement of the experimental package at minimally shielded areas of the payload carrier are desired to increase the number of HZE particle "hits".

DISCUSSION

GOALS AND OBJECTIVES

The major goals and objectives of the Space Biology Program are:

1. to advance our basic knowledge of the role of gravity in life processes and the capability of terrestrial organisms to adapt to gravitational changes

2. to understand the basic nature of biological rhythms in terrestrial organisms and their influence on life processes

3. to determine and assess the biological implications of galactic cosmic HZE particles for developing realistic radiation exposure guidelines and providing protective and/or preventive measures against particle radiation hazards for long duration manned space missions

4. to determine the potential applications and develop the techniques to utilize new advances in biological theories and space technology gained from research in the unique environment of space for space exploration and the benefit of mankind

5. to assess possible synergestic effect of gravity, magnetism and radiation on life's origin and evolutionary processes.

RESEARCH SUPPORT REQUIREMENTS

Space Biology as used in this report encompasses research on a wide variety of biological materials ranging from cells to complex multicellular animals. While animal models are also to be used for man-related studies, their research support requirements are considered here.

To develop the research support capability for experimentation in earth-orbiting manned laboratories, the requirements for Space Biology are organized around species with more or less common facility needs as follows: Cells and tissues (micro-organisms and cells in tissue culture), invertebrates, plants, and vertebrates. The most effective and least costly pursuit of this space research program would be to incorporate the biological research requirements with those of man-related studies in the development of a multifunctional life sciences research laboratory. This approach would utilize the many research functions, procedures, and analytical techniques common to biological and man-related studies.

The objective of the Life Sciences space research laboratory is to provide a facility (or facilities) capable of supporting biological as well as man-related studies and providing the flexibility for onboard modification of experimental protocols and the introduction of yet unidentified experiments with minimum impact on budget, flight schedules, or facility modification. The approach would be to develop a mini-lab for supporting carry-on experiments with an orderly growth in capability for supporting experimentation on shared as well as dedicated Life Sciences payloads in 7 and 30 day Shuttle Sorties and longer duration space station missions.

The Life Sciences laboratory would consist of three categories of equipment/facilities: A matrix of common operations research equipment/facilities (CORE) serving a broad spectrum of experimental areas in biology and in man-related studies; supplemental facilities and instrumentation relating to research support requirements which are sufficiently specialized to be removed from CORE; and experiment-peculiar items ancillary to either one or both of the above more general categories.

In the execution of the research programs, it is anticipated that the number and type of experiments being carried out at any one time would be consistent with the mission mode, capabilities and limitations of the payload carrier, and experiment compatibility.

Furthermore, the total laboratory facilities are not to be considered on an "all-or-none" basis. In a mission involving a Shuttle Sortie, for example, only those elements of the CORE and instrumentation/facilities required for given missions would be flown. Since the modular approach is to be used, research support capability could be readily adapted to meet any mission requirements.

Examples of common operations research equipment/facilities (CORE) for analysis, measurements, and data management are as follows:

- Biochemical/Biophysical Analysis Unit—with the capabilities for biochemistry, histochemistry, hematology, mass spectrometry, gas chromatography, electrophoresis, spectrophotometry, etc.

- Visual Records and Microscope Unit—with functional capabilities for still photography, cinematography, television, hard records, oscilloscope display/readout, electronic imaging, microscopic observations and records, micromanipulations, microscopic dissection, etc.

- Data Management Unit—with capabilities for data recording, storage or transmission, experiment management, subsystem control, electrophysiological and electromechanical transducer support, signal analysis and display, crew experiment task guidance, etc.

Examples of the service units of the CORE are:

- Life Sciences Experiment Support Unit—with the primary function of a supply and services interface between the space vehicle and Life Sciences Laboratory for providing transfer, distribution, control, and conditioning as required for crew environmental control and life support, and electrical and fluid utilities (includes electrical power, hardline data transfer, vacuum, water, purge and pressuant gases, process gases, thermal control fluids, and time signals, alarms, and other special communications).

- Preparation, Preservation, and Retrieval Unit—with functional capabilities for specimen autopsy, sample, specimen, and organism preservations, sample fixation, histological tissue sectioning, bacteriological and histological staining, microbial sampling and transfer, substrate (media) preparation, cleaning, sterilization, chemical storage and handling, etc.

- Maintenance, Repair and Fabrication Unit—for instrument cleaning repair and checkout, apparatus maintenance, modification and fabrication, cage cleaning and sterilization, etc.

- Ancillary Storage Unit—for general storage as well as for designated instruments and accessories.

The research support equipment/facilities which are peculiar to the biological research program and are considered to have major impact on the design and development of the laboratory are:

- Organism Holding Units (facilities)—separate ones for cells and tissues, invertebrates, plants, vertebrates, and subhuman primates.

- Organism Environmental Control and Life Support Subsystem (EC/LSS—for supporting organisms contained in the Holding Units and for isolating man from the organisms and different classes of organisms from each other.

- Organism Waste Management System; Laminar Flow Bench (LFB)—which may be considered as a modified portable glove box with a built-in laminar flow system to provide an isolated operational interface between the investigator (or payload specialist) and the organisms under study.

- Internal Bioresearch Centrifuge—with the greatest radius as feasible and vibration-free for providing gravitational force fields of $1 > g = 2$.

- Radiological Research Support Facility—required for both biological and medical uses—for irradiating biological specimens to onboard controlled radiation as well as to ambient galactic cosmic-ray particles, radioisotope tracer studies and diagnostic procedures of onboard personnel.

RESEARCH PROGRAM

The Life Sciences Space Research Program offers the biologist an unprecedented opportunity to advance basic knowledge in gravitational biology, biological rhythms and radiation biology of HZE particles. A prerequisite for flight experimentation would be well conceived and controlled experimental designs and comprehensive ground-based work, especially in gravitational biology and biological rhythms. Such work would be required to consider the influence of dynamic space flight factors such as vibration and acceleration/deceleration g-forces to be experienced by the experimental subjects at launch and reentry, respectively. This is especially important in short duration Sortie missions. The potential areas of research are described below under the appropriate categories.

Gravitational Biology

In gravitational biology, the areas of particular interest are to learn the mechanism by which terrestrial organisms sense gravitational force fields and to determine the role of gravity on life processes in general and in particular on growth and development of plants and animal. There is growing evidence that magnetic forces also play a role closely tied in with gravity. These cannot be completely separated on the ground. The specific roles of each and synergestic interactions can only be elucidated in a near-zero "g" environment.

The over-all research plan would be to consider the response processes at various g-levels, ranging from $g = 0$ to $g > 1$. Test subjects would be studied at $g \geq 1$ as part of the ground-based work, using centrifuges for $g > 1$. Clinostats would be used whenever practical, as in plants, for compensated gravity work. Space flight experimentation would extend these observations at $g \geq 0$. It would be scientifically sound to include observations at $g \geq 1$ in the weightless envirnment of space. Thus, an onboard biological research centrifuge with the greatest radius as feasible and vibration-free would be required for providing $1 > g = 2$. By providing organism holding units at appropriate locations on the centrifuge arms, it would be feasible to expose test organisms simultaneously to $1 > g = 2$ (e.g., 0.5, 1, 1.5, and 2 g). Since the centrifuge could have as many as 8 arms, it would be possible to test several species of organisms simultaneously.

Crucial experiments that require very-low "g" levels, approaching zero continuously, would undoubtedly require unmanned, free-flying satellites where the "g" variations introduced by the crewmember himself are absent. Such satellites (i.e., Life Sciences Research Module) could be launched from the Shuttle and retrieved in a subsequent Sortie.

Nearly all organisms use gravity for orientation. The mechanisms by which they sense and orient to gravitational force fields need to be clarified. This is especially true for higher plants. The sensors need to be physically identified and the principle of their function better understood. This area of study needs a full quantitative description of the overall stimulus-response process, including response kinetics. In animals, the sensors are much better defined than in higher plants, but their physiological role in maintaining posture and in sensorimotor coordination still raise questions of very general significance for biology and especially for neurophysiology.

The basic cellular functions required for optimum metabolism, growth and reproduction are generally taken for granted although not necessarily understood. Physical/chemical functions of the cells such as active and passive transport of nutrients or metabolic wastes across cellular membranes are not thoroughly understood. Research in development of life support systems has shown that gravity does affect ionic and non-ionic solute transport properties across membranes and solute/solvent gradients at the membrane interface. Does the same thing happen to cellular membranes? Is this changed in zero "g"? Does it affect calcium or potassium balance?

Single-cell organisms contain different mechanisms for gas exchange than do more highly developed plants and animals. Culture techniques vary, yet gas exchange kinetics are often poorly understood. Related enzyme/substrate reactions may vary in microgravity. For example, does the absence of bouyancy affect the enzyme product behavior for an enzyme such as catalase which has a gaseous end-product, oxygen?

Most, if not all of the basic principles in question for the development of life support systems, are directly applicable to the handling and behavior of single cell systems in zero "g".

The effects of gravity on life processes, especially on growth and development of micro-organisms, plants and animals, and the subcellular mechanisms that account for the effects need to be investigated. A broad spectrum of biological systems ranging from viruses and their hosts to multicellular animals will be needed on test subjects to clarify those phenomena attributed to the space environment. Examples of typical candidate experiments are presented in Table 1 and summarized by category in Table 2. Table 3 presents a concept of the experimental event schedule as it might be developed for a Shuttle Flight Experiment. This includes activities beginning with the initial experiment design proceeding through the preflight activities and concluding with postflight data and sample return. Table 4 presents an example of the experimental package functions and considerations, thus identifying those experiments that have similar needs.

Biological Rhythms

Biological rhythm studies in the space environment are important to clarify the mechanisms of biological rhythms, which are basic to almost all known living things, by divorcing them from terrestrial influences, and to the success and optimization of manned spaceflights.

Biological rhythms manifest themselves in many species and in many levels. Some processes, such as development and aging, vary unidirectionally; many others are cyclic in nature, with periodicities ranging from milliseconds to years.

The role of geophysical factors, such as solar and lunar cycles, as timesetters for biological rhythms is well known. These rhythms, circadian in nature, express themselves in essentially all groups of organisms at levels from the biochemical through the behavioral, and include variations in nucleic acid synthesis, various metabolic activities, body temperature, organ and organ system functions, periodicities of sleep and wakefulness, motor activity and feeding and the variations in response to drugs as a function of time within the circadian period. On a longer time scale, many organisms, especially marine invertebrates, show a strict relationship between the lunar cycle and their reproductive cycle. Yearly rhythms express themselves in the reproductive activities from fish to mammal and in changes in growth and differentiation rates among photosynthetic organisms even when they are kept under constant conditions.

While evidence is accumulating from carefully designed ground work that some of these rhythms are endogenous to the organism rather than entirely dependent on the environment, definitive studies in space removed from all conceivable geophysical influences are indicated to thoroughly understand the nature of biological rhythms. Although experimentation in low-earth Shuttle orbits would contribute significantly to our basic knowledge of biologic rhythms, crucial experimentation would require high elliptical orbits or deep-space probes to completely escape geophysical influences.

A wide variety of organisms from the unicellular to the multicellular will be used as test subjects. Examples of typical flight experiments are the two planned for Skylab A: "Circadian Rhythm of Pocket Mice" and "Circadian Rhythm of the Vinegar Gnat." The purpose of the pocket mice experiment is to determine whether the daily physiological rhythms (body temperature, heart rate, and activity level) of a mammal are altered by the space environment. The vinegar gnat (drosophila) experiment is to determine whether the daily emerging cycle of the pupae is the same in space as on the earth.

Other examples of candidate experiments are given in Table 2, and the assessment of plants as test subjects is considered below.

Only a few higher plants have been studied in sufficient detail to permit experimentation in spacecraft conditions to lead to valid conclusions. The characteristics are best defined for those plants that represent the transition between plants and animals, e.g., Euglena and Gonyaulax. However, it can be concluded that circadian rhythms occur in all groups of the plant kingdom. In the case of bacteria, their growth in long tubes has been said to be regulated by rhythmic factors, but the usual characteristics of circadian rhythms are not found within this group of organisms.

Regular fluctuations, and self-sustaining rhythms are expressed in regular movements of leaf position, fluctuations in the rate or activity of physiological processes such as carbon dioxide fixation, photosynthetic activity, emmission of light, shape, color of spores, and a variety of lesser known processes.

The effect of light is manyfold more important in establishment and entrainment. Red light and UV light are the most effective. The phytochrome system appears to be inolved, but it may not be the most important pigment in the control of circadian rhythms. The effect of temperature fluctuations is not great. The temperature effect is most noticeable during the one or two cycles following the radical temperature change, and is generally difficult to detect.

Conflicting evidence has been put forth on whether or not the clock resides in the nucleus of the plant cell. The rhythm has been shown to persist following removal of nuclei, yet it disappears when inhibitors or messenger RNA are applied to the plant cells.

The species investigated in detail include Phaseolus multiflorus (common bean in the United Kingdom), Bryophyllum fedtschenkoi (common bryophyllum), Oedogonium cardiacum (alga), Euglena gracilis (plant/animal alga), Acetabularia spp. (alga), Helianthus spp. (sunflower), Avena sativa (oats), and Gonyaulax polyhedra (plant/animal alga). The latter has been studied in the most detail for the enzyme luciferase (bioluminescence).

Procedures in measuring the movement of petals and leaves have been extensively studied, and experiments in spacecraft would be valuable provided care was taken to provide adequate air circulation. Experiments on Gonyaulax polyhedra could be accomplished readily in early Shuttle flights (suitcase experiments). Fixation of carbon dioxide, and production of root exudates, could be readily measured in the Shuttle Sortie flights.

The question of circadian rhythms in plants is of great practical importance because the limiting factor for growth of plants on earth is most often the amount of light available. Light flash experiments have led to entrainment of light/dark cycles, and are responsible for the uniform production of many seed and flower crops by commerical growers.

Radiation Biology

While exposure to low level HZE galactic cosmic-ray particles during short-term, low-earth orbital Shuttle Sortie flight may not be hazardous to crew members, exposures of long-durations during extended missions could possibly influence man's operation in space. The layout of the payload equipment and materials, and/or design and fabrication of space station, lunar base, and crafts for future manned planetary expeditions must provide maximum shielding against HZE particles. For these reasons, it is important and essential to accomplish meaningful ground-based and flight studies to derive more precise and definitive assessment of the biological implications of HZE particles. The biologic effects need to be correlated with the physical characteristics of the particles (e.g., energy and charge) and number of "hits".

Comprehensive ground-based studies are being conducted and need to be extended to establish baseline data on the acute and chronic effects of accelerator-produced heavy-ions. Emphasis is placed on determining the LET-effect in a variety of biological materials ranging from seeds, cells and tissues, invertebrates, and animals; and exposing the materials to low flux, low dose levels of heavy-ions. The approach is to determine the effective exposure levels for induction of significant biologic effects by various Z particles. Included are studies to determine pathologic effects induced in non-proliferating neurons in tissue culture as well as in brains of intact organisms; effects on recovery potential of rapidly proliferating cells and tissues and on the growth, development, mutation, and behavior in developing organisms; and chronic effects, with emphasis on oncogenesis, in sublethally irradiated animals.

Space flight experiments will determine and confirm ground-based work as well as assess the biological effects of HZE particles currently not available for study with accelerators. Current work includes the Biostack experiment, flown on Apollo 16 and is also scheduled for Apollo 17, to study the effects of HZE particles on embryogenesis, growth, development and morphogenesis in brine shrimp and plants exposed at the encapsulated cyst and seed stages, respectively. Also to be flown on Apollo 17 is the Biocore experiment, designed to ascertain whether HZE particles induce discernible pathological lesions in the brain and eye of a small animal. Additional spaceflight experiments are definitely required to analyze and evaluate the biological effects of the different species of HZE particles prevalent in space. Every flight opportunity (including Shuttle

Shortie missions, free-flying modules, and space station) should be utilized for this purpose.

Table A-1

Candidate List of Experiments to be Used in Obtaining Fundamental Data on the Effect of Microgravity and the Space Environment on Biological Systems

1. Maintenance of Normal Growth and Reproduction of Free Cells in Mass Culture in Weightlessness Over Extended Periods of Time

   Rationale: Data can serve as basis for bioregenerative life support systems and in production of large quantities of metabolic products through fermentation or selective nutrient breakdown.

2. Effects of Weightlessness of Mineral Metabolism in Microbial Cells

   Rationale: To determine what specific minerals are essential for growth when at one G and when at micro G. Relate to K^+ and Ca^{++} metabolism in mammals.

3. Comparative Effects of Induced Mutations in Microbial Cells

   Rationale: Provide basis for enlarged study on behavior of known mutagens in higher animal cell systems.

4. Effects of Space Environment of Periodicity of Growth and Conidial Formation in Fungi

   Rationale: To develop fundamental basis for extended studies of effects of space environment on circadian rhythms of more complex organisms leading to studies on man.

5. Effects of Weightlessness on Molecular Reactions in Vitro

   Rationale: Obtain basic data on the behavior of molecular systems fundamental to the proper function of cellular processes (eg. active/passive diffusion).

6. Ultrastructure of Prokaryocytic Cells for Possible Inheritable or Somatic Abnormalities

Table A-1 (Continued)

Rationale: Define those areas of further investigation to understand what expected changes will occur when using prokaryocytic cells in a biological system in space.

7. Aging and Growth Rate of Neurospora spp

Rationale: Already well documented information on aging and growth rate of Neurospora spp at one G can be compared with any alterations occuring at micro G.

8. Growth Rate and Yield of Selected Bacteria

Rationale: Elaborate on data from Biosatellite II which indicated an increased growth rate of bacterial cells in a micro-gravity environment.

9. Growth Rate and Yield of Bacterophage and Virus

Rationale: Determine if increased rate of lysis in weightlessness increases intercellular product yield.

10. Lysogeny - Latency

Rationale: Examine those parameters of lysogency - latency which are affected by weightlessness.

11. Cell Division and Morphology

Rationale: Determine if weightlessness alters plane of division of microbial cells producing an altered morphology.

12. Enzyme-Substrate Product Interaction

Rationale: Study effect of altered contact with substrate due to weightlessness in production of specific enzymes.

13. Exposure of Microbial Cells to Elements (Heavy Metals) Not Normally Involved in Living Systems

Rationale: Availability of heavy metal catalysts in weightlessness for possible utilization by microbial cells in synthesis of new enzymes.

Table A-1 (Continued)

14. Effect of Space Environment on Intranuclear Metabolism of Cells

    Rationale: Determine roll of gravity in maintaining nuclear integrity in eucaryotic cells.

15. Inheritable and Somatic Abnormalities in Eucaryotic Cells

    Rationale: Determine what effects space environment has on these easily studied parameters. Relate information obtained to higher biological systems.

16. Embryology Experiment

    Rationale: Important to gain understanding for possible long term space flights or self sustaining ecosystems.

17. Circadian Rhythms and Biorhythmicity in Invertebrates During Orbital Flight

    Rationale: Determine ability which an organism can either maintain or adapt its rhythmic physiological functions over an extended period of weightlessness.

18. The Role of Gravity in the Function of the Invertebrate Organism Throughout its Life Cycle

    Rationale: To observe the effect of weightlessness on all parameters in the life cycle of an animal. Can relate to long term manned space flights.

19. Role of Gravity on Morphogenesis in Invertebrates

    Rationale: Define more closely the nature of morphogenetic anomalies found in earlier space flight.

20. Role of Gravity on Aging in Invertebrates

    Rationale: Determine what effect weightlessness has on normal aging process.

21. Role of Gravity on Genetic Phenomena in Invertebrates

Table A-1 (Continued)

	Rationale: Elucidate role gravity plays in maintaining genetic stability in organisms.
22.	Role of Gravity on Behavior Patterns
23.	Role of Gravity on Maintenance and Reproduction of Animal Tissue Cells
24.	Molecular Movement Through Cytoplasm
25.	Secondary Wall Development, Cell Differentiation
26.	Cytoplasmic Streaming
27.	Cellular Polarity in Plant Tissue Culture
28.	Auxin Experiments IAA Diffusion
29.	Circadian Leaf Movements and Biological Rhythms in Living Plants
30.	Random Tumor Tissue Growth
31.	Plant Growth Characteristics

Table A-1 (Continued)

32. Plant Morphogenesis
33. Dorsoventrality
34. Land Plant Evolution - Lignification
35. Maintenance and Reproduction of Algae Cultures
36. Maintenance and Reproduction in Plant Tissue Culture

Table A-2

Summary of Candidate Experimental Categories and Applicable Research Organism for Study in Space Environments (Numbers Refer to Experiment Listed in Table A-1)

Category	Morphology			Growth		Metabolism			Genetics			Life Cycles		
	Ultra-Structure	Cellular	Morpho-Genesis	Rate	Yield	Rate	Yield	Alterations	Mitosis	Meiosis	Mutation	Biorhythm	Aging	Viral
Microbial														
Bacteria	5, 6	6	11	1, 8	1, 8	2	2	2, 12, 13			3			9, 10
Virus	6			9	9						3			
Fungi	6	6	7	1, 7	1	2	2	2, 12, 13	7		3	4	7	10
Yeasts	5, 6	6	11	1	1	2	2	2, 12, 13			3		7	
Animal														
Normal Cells	14, 23	14, 23	19, 23	23	23	14	23	14	15	15	15		23	23
Neoplastic Cells	14, 23	14, 23	19, 23	23	23	14	23	14	15	15	15		23	23
Protozoa	14	14				14			15	15	15	15	15	
Invertebrate	16, 18	16, 18	16, 18, 19	16, 18		16, 18						17, 18	18	
Plant														
Normal Cells	24, 36	25, 26, 36	25, 27, 32 36	36	36	28, 36	28, 36	28, 36	36		36	31	31	36
Callus Cells	30, 36	30, 36	30, 32, 36	30, 36	30, 36	30, 36	30, 36	30, 36	30, 36		30, 36	31	31	36
Tissue		26	25, 27, 32			28	28	28			26	29	29, 31	
Algae	24, 35	24, 35	35	35	35	35	35	35			35	35		

Table A-3

Example of Candidate Experimental Event Schedule for Shuttle Flight Experiments

		Package Environmental Requirements				Package Hardware Requirements — Sampling				
Event	Time of Event	Physical State	Temp.	Atmosphere	Growth Chamber	Data Measurement	Chem. Pres.	Freeze Dry	Data Ret.	Remarks
Experiment Design	6 mo. to 1 yr. prelaunch									Interface with hardware design
Prelaunch preparation	120 hours prelaunch	Freeze dried liquid DW	$<110°F$	Sealed 5×10^{-2} Torr.						Not influenced by launch delay. No constraints during launch
Experimental Initiation (rehydration)	At deployment of orbiter	Combination of water and solid	35°C	Aerobic, Anerobic	X				X	Telemetered signal to indicate experiment mixing
Zero Time Sample	Post deployment TBD (<30 min.)	Liquid	35°C	Anaerobic Aerobic	X	X	X	X	X	
Growth Rate Sampling	At 2 hour intervals post deployment	Liquid	35°C	Anaerobic Aerobic	X	X	X	X	X	
Final Sample	38 hours post deployment	Liquid	35°C	Anaerobic Aerobic	X	X	X	X	X	
Experiment Shut Down	18 hours plus TBD minutes after final sample*	Samples freeze dried or chemically preserved	$<110°F$	Sealed	TBD**	TBD**				No constraints during re-entry, splashdown, and retrieval except max. tem. 110°F

*Minutes required for sampling, data measurements and sample preservation to be determined (TBD)
**Final disposition of growth chamber and densitometry measuring device to be determined (TBD)

Table A-4

Example of Experiment Package Functional Requirements and Considerations

Experiment No.	Environmental Control				Inflight Data Measurement Frequency		Inflight Sampling					Package Function as Related to					
	Atmosphere		Temperature				Frequency		Preservation			Prelaunch and Recovery Constraints			Launch and Return Constraints		
	Aerobic	Anaerobic	28° C	35° C	Constant	Intervals	Intervals	None	Freeze Dry	Chemical	Freeze	Temp.	Time	None	Accel.	Vibration	None
1	X	X	X	X	X	X	X		X	X				X			X
2	X	X	X	X	X	X	X		X	X				X			X
3	X	X	X	X		X	X		X	X				X			X
4	X		X			X	X			X				X			X
5	X	X	X	X	X	X	X		X	X				X			X
6	X	X	X	X		X	X			X				X			X
7	X		X			X	X		X	X				X			X
8	X	X		X	X	X	X		X	X				X			X
9	X			X	X	X	X		X	X				X			X
10	X			X		X	X		X	X				X			X
11	X	X	X	X		X	X			X				X			X
12	X	X	X	X	X	X	X		X	X	X			X			X
13	X	X	X	X		X	X		X	X				X			X
14	X		X			X	X			X	X	X	X				X
15	X		X			X	X			X	X	X	X				X
16	X			X		X		X		X		X	X				X
17	X		X			X		X		X		X	X				
18	X		X									X	X				
19	X		X	X								X	X				
20	X		X	X		X						X	X				
21	X		X			X						X	X				
22	X		X									X	X				
23	X	X		X	X	X	X			X	X	X	X				X
24	X		X			X	X			X		X	X				
25	X		X			X	X			X							
26	X		X				X										
27	X		X							X		X	X				
28	X					X	X		X	X							
29	X		X		X	X	X			X							
30	X		X			X	X			X							
31	X		X		X			X			X						
32	X		X					X		X	X						
33	X		X														
34	X		X														
35	X		X		X	X	X			X		X	X				
36	X		X		X	X	X			X		X	X				

APPENDIX B

PLANETARY BIOLOGY

EARTH ORBITAL PARTICLE COLLECTION FOR CHEMICAL (ORGANIC AND INORGANIC) AND PHYSICAL ANALYSIS

The Shuttle provides a means of collecting particulate matter in space which may be trapped in earth orbit. The presence of organic matter in association with dust particles in space has recently been confirmed by radio astronomy. The types of molecules present, the mechanism of synthesis and stability of these organics are of fundamental importance to theories of chemical evolution and the orgin of life. Direct collection of particles which are definitely uncontaminated by spacecraft outgassing and organics will be analyzed on recovery. A sampling device should be flown routinely in every mission.

PLANETARY AND INTERPLANETARY PROBE LAUNCH

The Shuttle can serve as a launch platform for:

- Mars Launch Missions—Automated follow-on Viking-type missions, to study the planet in detail from the point of view of characterizing the planet's biology, geology, meteorology, chemistry, etc. Experiments can be designed based on Mariner 9 data and later on, Viking data. A Shuttle launch makes possible larger scientific payloads and launches in years not feasible for earth-launched missions (e.g., 1980's to Mars), with existing systems. A Shuttle launch affords two launches per year opportunity to Mars - 1979, 1981, 1983, 1985, etc. The duration of the program depends on data obtained in early missions. The Shuttle ultimately also provides the means of returning Martian or other extraterrestrial samples to the earth - after appropriate quarantine in earth orbit.

- Jupiter Missions—Jupiter orbiters and/or atmospheric probes to study the organic chemistry of the atmosphere can be launched effectively from the Shuttle. There are data indicating that organic molecules may now be synthesized in the Jovian atmosphere, and therefore Jupiter may provide contemporary evidence of chemical evolution in our solar system.

- Titan Missions—Titan, one of the satellites of Saturn, is large enough to have an atmosphere which is composed of methane. The surface of Saturn (unlike Jupiter) is cold enough that organic molecules synthesized non-biologically in the atmosphere, would condense on the surface. Analysis of this material by means of instruments landed on Titan can make a very real contribution to our understanding of chemical evolution and the origin of life.

- Comet Missions—Organic matter, which may be remnants of the primitive solar nebula can be seen spectroscopically in comets. Acquisition and analysis of the material in the tail of a comet can be done by a "fly-through" mission, launched from the Shuttle. The nature and amount of organic material in comets is fundamental to understanding chemical evolution.

- Asteroid Missions—The asteroids may be the parent bodies of the meteorites, including the carbonaceous chondrites. The chondrites contain organic matter; however, all meteorites on earth have been subjected to various degrees of contamination. Analysis of uncontaminated meteoritic material could be accomplished by an asteroid mission, which can also tell us more about the origin of meteorites and the importance of such organic matter to understanding chemical evolution in the solar system and the orgin of life.

APPENDIX C

BIOMEDICINE

MAN-RELATED STUDIES

The shuttle will provide new opportunities to study the effects of the unique environment of space on body systems. Work in this area will extend our inquiries into areas of concern which have been highlighted from previous flight programs. Investigation will be directed toward the determination of man's capability to adapt to the space flight environment as this will have an impact on his ability to perform as a crew member, worker, and investigator during near and long-term orbital flight, and eventually for planetary exploration. Specifically, it is anticipated that further work will be required on those organ systems which have been found to be influenced by gravity by previous flights; namely, the cardiovascular, vestibular, and musculo-skeletal systems. The effects of low earth orbital flights on biological periodicities, especially those affecting physiological systems, also need to be studied. Finally, it can be assumed that the increased complexities of flight missions and the increased frequency of such missions will raise questions concerning the selection of flight crew members, their inter-personal relations, and the effects of behavioral and physiological changes on the adaptability of the human operator to perform effectively in these missions.

Each flight, regardless of duration, affords an opportunity to gain new knowledge. The scope and magnitude of any investigations will increase progressively with time. A dedicated Life Sciences Laboratory is required to gather sound scientific evidence in order to explain the behavior of human body systems during long duration space flight.

Even though many observations on a large number of individuals are anticipated during a short duration of flight exposure, they are not expected to produce the data necessary to qualify man for long duration space flight. These initial observations, however, will have influence in the near term by verifying ground-based studies, and by providing information about fundamental mechanisms which are expected to be altered with long duration flight.

The on-going or continuous program will utilize animals as well as man, whenever possible. Animal models will provide information concerning basic mechanisms not easily determined in man. Such animal models would provide information in areas where measurements have not been developed for use in humans or would carry a significant hazard if utilized in man.

PHASE A

Initial Shuttle flights will be confined to sample collection, hopefully utilizing all crew members (urine, blood, status monitoring). As many subjects as possible will be utilized in order to obtain a large pool of data and to establish statistically significant norms and verify ground-based data. The first available flights and all flights thereafter should be utilized. All samples will be analyzed in ground-based laboratories. The findings from these studies will influence the course of future work.

PHASE B

As the number of human subjects is increased per flight, the specific investigations on human bodily functions will be increased, using invasive and non-invasive methods. Data will be obtained on body systems known to be affected by the space environment (cardiovascular, vestibular, musculo-skeletal). Statistically, significant numbers will be needed in order to make valid judgments. Without a dedicated laboratory, however, the scope of research will be severely limited. These measurements will complement and validate animal models.

PHASE C

The multidisciplinary scientific objectives, the increasing numbers of crew members, and the mission durations projected for the Shuttle era pose an associated series of new selection, health maintenance, and behavioral efforts. Increasing demands on the unique talents of man appear to characterize the Shuttle flights. It is recognized within the scope of this report that the previous empirical or pragmatic approaches will not adequately provide for this new relationship of man to the mission. Informational and developmental requirements dictate that the resulting data base upon which decisions will be made must be of sufficient depth to permit statistical confidence for the future of manned space flight.

A laboratory dedicated to biomedical research is required for indepth human and animal studies in order to determine basic mechanisms of adaptation to space flight. It is anticipated that, at least, one dedicated flight per year, in addition to each flight opportunity, will be required in order to provide information to create realistic predictive models or design protective devices. It is strongly recommended that these functions be provided as early as possible in the program.

On the basis of the factors derived from the research activities, the need for countermeasures and the relative effectiveness of a given countermeasure proposal compared to another will be determined. The countermeasure study program is so structured as to produce the information necessary for definition of countermeasure approaches, their effectiveness, and proposed use. A laboratory will also allow the testing of countermeasures to prevent the physiological deconditioning that occurs with space flight.

PHASE D

One of the major scientific objectives of the Life Science program for manned space flight is to acquire, analyze, and interject data relevant to the problems of human performance capability and behavior in space. Space missions of the past have tended to be more concerned with the applications aspects as opposed to the scientific investigations of man in space. Data reflecting in space human performance capability and limitations and human behavior (including group behavior and individual crew member behavior, attitudes, motivational levels, anxieties, etc.) are required to expand our understanding of the human organism as well as to provide guidelines and criteria to system design engineers. The weightless, more or less confined, and isolated conditions of spaceflight offer an opportunity to investigate the abilities, reactions, intellectual processes, and social behavior of man in a still novel and always hostile environment.

Although increased emphasis must be placed on the scientific investigation of man in space, this change in emphasis cannot degrade the importance of measuring man for purposes of proving and improving the man-machine interface technology. A primary objective of human performance flight experiments in the Shuttle era must continue to be directed to the need to establish operator capabilities and requirements as they impact total system performance and crew safety. Thus the man in space must be considered from two different although related orientations: as a human organism requiring scientific investigation and measurement; as an important element of a flight system whose performance capability is reflected in the performance level of that system, and whose safety is of primary concern in any manned system.

DISCUSSION

There are two distinct facets to the Man-Related Studies of the Shuttle era. One facet directs its effort in investigations towards the collection of high-fidelity, high-quality data on the new population of space flight participants in order to substantiate the original medical selection criteria being developed for Shuttle passenger selection. The other facet of study and investigation will be to expand the understanding of physiological mechanisms which have been observed to date in manned space flight and will unquestionably arise as a result of the investigations being conducted in flight on Skylab.

It has been established as NASA policy that a diverse population of scientists and/or passengers will participate in the Shuttle Sortie flights. The Life Sciences SR&T Program is currently supporting research and associated study efforts which eventually will provide the medical selection criteria from which the medical standards for Shuttle scientist/passenger selection will be made. There is no doubt that the original standards will tend to be conservative from both a safety and insufficient experience position. It will be extremely important and advantageous to collect high quality data on these individuals in statistically significant quantities in order to substantiate standards implemented and, more importantly, to gain sufficient evidence for relaxing what will be admittedly conservative standards.

It is also reasonable to assume that there will be certain selected medical and/or physiological parameters which should be measured on both crew members and non-crew members. The minimum foreseeable standards at this point in time would be accurate measurements of such basic but important parameters as intake and output plus body mass measurement.

Until such time as the commitment of man in space flight becomes a routine non-Government sponsored activity, it will be incumbent upon NASA to insure the medical safety and protection of those participating in space flight.

While the Life Science Payload Panel members agreed that performance data on the man in space are required, they indicated that a more effective and efficient manner of acquiring such data is through the application of non-interference measurements. These measurements generally involve data collected on operator performance as he conducts those activities associated with his mission, as opposed to the use of a special test device to measure perceptual, motor, and cognitive performance. Since man will be included in a wide variety of Shuttle and Sortie missions in addition to those proposed to support the Life Science discipline, and since a large quantity of data will be required to offset the reduced opportunity to apply experimental controls, it was recommended that human performance data be acquired for missions involving other disciplines in addition to the life sciences missions. Effort still needs to be expended on identifying specific measurements and required conditions at the time of measurement. It was the opinion of the panel members concerned with the question of human performance assessment that a well conceived and planned data acquisition program over a range of different Shuttle and Sortie missions would provide the answers to basic questions of performance capabilities and limitations of man in space. It was also recommended that the performance data acquisition program be integrated with the biomedical and physiological data sampling activities. Their data and their interrelationships will be used to monitor the crews during the conduct of a mission and to identify and isolate performance limits and problem areas in a post flight analysis.

While the on-line data acquisition approach was preferred over the use of standardized performance tests, such tests should not be deleted from further consideration at this time. The problems usually associated with standardized tests are those of crew acceptance, crew motivation, and the general absence of face validity or relevance of the test to operational requirements. However, use of such tests does in theory assure collection of performance data under carefully controlled conditions and in a quantity amenable to statistical analysis and prediction. For these reasons the Panel recommends that the performance data sampling described above be augmented with the use of specially designed simulation exercises. These exercises would make use of a work station mockup and visual display generation equipment to enable the in-flight simulation of any one of a number of flight phases or experiments. At the station a crewman would practice simulated Shuttle landing maneuvers, or simulated rendezvous and docking, or tracking of a simulated solar flare, or identification of geographic patterns for an earth resources experiment, etc. While the operator uses the simulator, data reflecting his performance capability to perform simulated activities will be acquired and recorded. Thus the simulator would serve three basic functions:

1. It would provide an opportunity for preview and practice of a mission segment or of an experimental reference.

2. It would offer an opportunity for off duty recreation, which is important for longer duration missions.

3. It would provide a means to acquire performance data under controlled conditions on a periodic basis.

The final area considered by the Life Sciences Panel in man-machine integration/human performance, was the requirement to assess and interpret interpersonal relations, group dynamics, and the psychological integrity of an individual crewman. The panel agreed that these items are important both from a scientific and crew maintenance point of view. However, the panel also noted the general inadequacy or unreliability of measures and tests available today in fields of psychiatric monitoring and the psychology of small groups. The panel recommendation is to seek the consultation of scientists in these fields to identify the requirements and methods associated with an in-flight assessment.

APPENDIX D

LIFE SCIENCES-ADVANCED TECHNOLOGY

LIFE SUPPORT SUBSYSTEMS AND PROTECTIVE DEVICES

The NASA SRT program in this technology area is dedicated to developing regenerative life support subsystems and advanced protective devices for manned space flight. These advanced subsystems and devices are required for future manned spaceflight beyond the Skylab and Shuttle Sortie missions. (e.g. modular space station and manned interplanetary missions.)

The life support subsystem and crew protective technology areas include: air revitalization, water and waste management, crew protective equipment, and food technology. These technology areas utilize membrane transport processes, absorption processes, phase change processes, electrochemical processes, other physical and chemical processes and bioregenerative processes.

Liquid phase membrane transport processes have demonstrated, in ground based tests, that gravity does affect ionic and non-ionic solute rejection properties, solute/solvent gradients at the membrane surfaces, and free convection cells. Studies are required on liquid phase membrane transport processes to measure solute rejection rates and transport coefficients in zero "g". These studies are required for advanced life support development for manned spacecraft and will also aid in understanding the behavior of living cells in zero "g". Real time analysis would be required for such an experiment. Data from a 7-day Sortie flight would make it possible to evaluate phenomena that are not time dependent, and a 30-day Sortie flight is necessary to evaluate time dependent phenomena.

Gas phase membrane transport processes also demonstrate gravity dependent characteristics (such as concentration polarization) similar to liquid phase transport processes. Understanding of gas phase membrane transport process is also essential to advanced life support development and also to cellular biology studies. Zero "g" tests similar to those specified for liquid phase membrane transport processes are required.

Absorption phenomena such as gas/solid and liquid/solid absorption and the reciprocal desorption phenomena are affected by gravity. Absorption and desorption processes are required for advanced spacecraft life support systems and for Portable Life Support System (PLSS) applications. Engineering information applicable at 0-1 "g" is required in order to understand solute and gas absorption phenomena. This information is required in order to design and fabricate reliable and more efficient non-regenerable and regenerable sorber systems for manned space use.

Electrochemical processes are required to perform many advanced life support functions (CO_2 removal O_2 generation, urine pretreatment, etc.). These electrochemical processes utilize a matrix material that contains an electrolyte in contact with two electrodes; and the electrode/electrolyte interface controls the ultimate performance of the process. Gas is either absorbed or evolved at this interface and electron transfer also takes place at this interface. The gas/liquid phase change is affected by gravity as are the gas absorption process, the diffusion process through the electrolyte, and the gas evolution process. The electrochemical performance of such devices must be tested in zero "g" to evaluate these parameters. This engineering data is required for the design and construction of advanced life support subsystems for manned spacecraft.

Gas sampling methodology must be evaluated in zero "g". This is required to provide accurate monitoring information on hazardous and non-hazardous gases and to provide accurate signals to the spacecraft life support system controls. This methodology must be evaluated not only for application to the crew quarters but also to equipment enclosures. For example, some life support subsystems utilize and/or produce hazardous gases, ex. H_2. If any gas leaks do occur, the gas monitoring system must detect such a leak before any localized cabin gas concentration reaches a hazardous limit. These leaks could occur in a spacecraft area (equipment enclosure) that is not actively ventilated and only gas diffusion (brownian movement) occurs. Detection of gases in such areas is especially critical to avoid hazardous limits, and impacts on equipment design, packaging and safety considerations.

Bioregenerative life support subsystems have had a limited amount of development support because of the higher priority for closing the oxygen and water loops in a spacecraft life support system. Bioregenerative subsystems require gas absorption by liquids, gas diffusion in liquids, gas and solute diffusion through cellular membranes, and other cellular behavior in a liquid suspension. A zero "g" experiment with a uni-cellular micro-organism, such as Chlorella, is required in order to determine if a reliable spacecraft subsystem can be designed and constructed. This type of experiment requires a facility for attaching biological life support modules to the cabin for actual test of in-flight performance. This will require the prefabrication of alternative pieces of flight flight hardware for study on the ground prior to committing to space flight. Inherent in this approach is the use of redundant physical systems which will provide for flight safety.

The Shuttle Sortie offers the only opportunity to perform these essential experiments. Some of these experiments can be Shuttle carry-on experiments in the 1979-1981 time frame and the other experiments should be performed on 7 and 30-day Sortie missions. The majority of gravity-dependent phenomena can be demonstrated on 7-day missions, but long-range degradation phenomena will require the 30-day flight. These experiments can be performed on a life science dedicated module or on a shared module.

The final design of a modular space station is scheduled for 1984. Therefore, the frequency of life support and protective device experiments is high during the 1979-1983 time frame and is decreased from 1984 through 1989. Flight experiments in this area are required beyond the 1984 time frame in order to test advanced life support concepts and advanced protective devices that have been developed due to increasingly stringent biomedical requirements for manned flight. (e.g. lower CO_2 partial pressure requirements.)

EXTRAVEHICULAR ACTIVITIES (EVA) TECHNOLOGY

In flight experiments of EVA are required for two purposes: to measure the performance of the man in the EVA system, and to evaluate and validate the design principles of the system and the man-machine interface. The subsystems of an EVA system include the space suit and life support systems, crew and cargo transfer devices, restraints and stabilization aids, tools, lighting systems, the work station, and the man himself.

Experiments will be required to cover a wide range of potential EVA applications. These applications will include:

- Spacecraft servicing, resupply, and update
- Cargo handling and transport
- Inspection of structures and components
- Assembly of structures
- Experiment support (data acquisition and measurement)
- Astronaut rescue

At present, three modes of operation are being considered to enable the EVA astronaut to perform these missions. These include EVA in free space, use of an integrated mobility system such as the astronaut maneuvering unit or the maneuverable work platform, and use of the Shuttle attached manipulator in a cherry picker mode to translate and position the EVA astronaut.

The EVA flight experiments will evaluate the relative effectiveness of each of these modes as well as establishing the astronaut and system performance capability for selected missions in each mode. The specific experiments developed to satisfy the latter objective will include controlled investigations of astronaut and hardware system performance capability to perform such activities as:

- Film magazine removal and replacement
- Experiment module removal and replacement
- Experiment module handling, emplacement, and transfer
- Experiment setup, activation, operation, and monitoring
- Fault identification and troubleshooting
- System checkout
- Erection and assembly of antennas
- Active cleaning of contaminated surfaces
- Inspection of spacecraft surfaces and components
- Collection of data and measurement in support of experiments conducted in free space
- Use of alignment, maintenance, and repair tools
- Use of work station controls and displays
- Maintaining stabilization at a work station
- Maneuvering from one station to another
- Performing emergency egress and escape from a work station
- Performing simulated astronaut rescue

The Life Sciences Payload Panel indicated that, at least in early flights, the EVA experiments could be conducted within the Sortie lab with the astronaut in a fully pressurized suit. In this implementation, a task board would be incorporated to simulate the worksite and controlled experiments would be conducted using the task board to simulate the EVA operations of interest. It is apparent that this configuration, with the man inside the lab, actually relates to only one of the EVA modes under consideration, i.e., the astronaut in free space. It is expected that experiments involving the other modes (astronaut on board the attached manipulator and astronaut with an integrated mobility device) would be conducted on later Shuttle missions.

The data to be recorded from these experiments will include engineering indications of hardware status, and measures of EVA system performance. The performance measures will include information on system accuracy, time to perform, and energy expenditure (metabolic rates, fuel, power). Data will be used to:

- Validate ground test program outputs
- Establish the performance limits of alternate system configurations
- Update and modify design criteria, operational procedures, and training programs
- Modify plans for experimental and operational EVA on subsequent missions.

Although experiments planned for the Skylab missions (e.g., M-509), will provide some of the information required to design operational systems to enable the astronauts to work effectively in space during EVA Sorties, additional inflight experiments are required to develop EVA technology more nearly responsive to currently projected EVA needs. The Sortie module and the pallet area (after payload deployment) offer an excellent opportunity to evaluate advanced EVA maneuvering systems, tether devices, space tools, and other work-site devices designed to assist the astronaut in the performance of tasks during EVA Sorties. Since EVA support is projected for all low earth-orbital manned missions, including early Shuttle missions, contunuing in-flight experiments to develop the EVA technology base and astronaut experience are required. Increased frequency (i.e., 2/year), is indicated for the 1979-1981 time period to reflect the urgency in improving EVA technology in the near-term to support early Shuttle missions.

TELEOPERATOR TECHNOLOGY

An experimental free-flying teleoperator system is currently proposed for use as a prototype or experimental system, deployed from the Shuttle in 1979, to study the utility of this type of system to support both early operational missions of the Shuttle as well as future earth orbital missions. A teleoperator is defined operationally as a remotely controlled, cybernetic, man-machine system designed to extend and augment man's sensory, locomotive, and manipulative capabilities. The free flying teleoperator is a small unmanned flight vehicle capable of operating in proximity to the Shuttle or in geosynchronous orbit in conjunction with the tug. In either case the vehicle is controlled by man located either in the Shuttle or, in the case of the geosynchronous orbit missions, on the ground.

The Free Flying Teleoperator, or FFTO, will comprise one of two Life Sciences Shuttle payloads, the other being the bioresearch module. The FFTO is considered a Life Sciences payload by virtue of the fact that it is inherently a man-machine system. It depends on man for control inputs and it exists for the purpose of extending man's unique capabilities beyond his physical presence.

The major systems of the FFTO include the following:

<u>Manipulator System</u>

- Spacecraft grapplers and stabilization devices
- General purpose manipulator arms
- Special purpose manipulative devices
- End effectors or manipulator "hands"

<u>Sensor System</u>

- Visual

    Video sensor, monitors, and processing
    Worksite illumination
    Spacecraft markings, targets, and aids

- Force feedback
- Tactile/contact sensors

- Guidance and navigation sensors

    Acquisition sensors
    Ranging aids
    Man aids

- Obstacle detection/avoidance sensors

- Spacecraft dynamics measurement sensors

<u>Mobility System</u>

- Structures

- Propulsion

- Power

- System integration

<u>Control System</u>

- Controllers — manipulator and mobility systems

- Man-computer interface

- Control/feedback integration

- Control station

- Control laws, logic, coordinate systems

<u>Communications</u>

- Control with time delay for geosynchronous missions

- Video processing

<u>Spacecraft Interface</u>

- Attach points

- Beacons and reflectors

- Visual aids

The FFTO is not considered to be a competitor to either the astronaut performing EVA, or to the Shuttle-attached manipulator system. Each of these three approaches has its unique capabilities and limitations and there are missions where only one approach is applicable. Including the FFTO with the EVA and the attached manipulator as a candidate means of satisfying Shuttle and Sortie mission requirements provides NASA with another dimension of capability.

Although it is a Life Sciences payload, the FFTO will interface with a wide variety of spacecraft and payloads associated with other scientific and applications disciplines. It will be used to capture and retrieve stable and unstable spacecraft. It has applications for performing on-orbit maintenance, repair and update of spacecraft. Due to its free flying capability it is capable of inspecting the entire external surface of a spacecraft, i.e., the Shuttle itself. The FFTO has application for cargo transfer activities and even for crew transfer in a rescue mode. The system is being considered as a candidate method of supporting experiments which require remote operation from the Shuttle by reason of safety, contamination factors, or requirements for a large area of activity. In conjunction with the tug the FFTO is being considered for delivery of spacecraft to geosynchronous or high earth orbits and for capture, retrieval, and servicing of spacecraft in such orbits. The applications of the FFTO are therefore numerous and varied. The use of the FFTO brings to the Shuttle an added dimension of versatility, flexibility, safety of operations, effectiveness, and economy.

<u>FFTO Flight Evaluation</u>—An effort is currently underway at Marshall Space Flight Center to define and describe a flight evaluation program for the FFTO to be conducted on early Shuttle missions. The objective of the flight evaluation is to verify and demonstrate the capability of the system, and specifically the man in the system, to perform intended missions. The proposed missions of the FFTO to be investigated in the evaluation include the following:

- <u>Capture and retrieval of a small spinning satellite</u> — the Life Sciences Research Module or LSRM
- <u>Capture and retrieval of a medium size passive satellite</u> — the Micrometeorite Exposure Module or MEM
- <u>Deployment and emplacement of a small satellite</u> — LSRM
- <u>On orbit servicing and update</u> — LSRM, MEM, High Energy Astronomy Observatory or HEAO, and Shuttle
- <u>Spacecraft inspection</u> — inspection of the Shuttle heat shield

- Experiment support — use of the free flying teleoperator as a subsatellite in several of the space physics and communications/navigation laboratory experiments.

  —deployment and erection of antennas for the communication/navigation laboratory.
  —measurement of contamination levels in the vicinity of the Shuttle
  —measurement of the plasma wake of the Shuttle
  —active cleaning of optical surfaces
  —astronaut support - cooperation between FFTO and an astronaut in EVA
  —astronaut rescue

During the conduct of these evaluation exercises the human operator will be located in the Shuttle, either in the orbiter cabin or in the Sortie lab. The number of operators required is still open to question at this time although it is anticipated that the system will be designed to accomodate only one operator.

The data to be acquired from the in-flight evaluations will be used to structure the capability limits of the system, to identify problem areas in design or procedures, and to assist in the planning of future FFTO missions. These data will serve these uses directly and also in conjunction with performance data acquired in ground based simulations. In the latter application, the data will provide benchmarks for validation and update of the ground test data.

The flight evaluation data to be recorded will be of four basic types: real time feedback data; information on existing conditions at the time of the evaluation; system engineering data; system performance measures. The real time data recording will basically include videotaping of the visual image displayed to the operator. The data on existing conditions will include planning data, sun-Shuttle-FFTO geometry, spacecraft-FFTO range and relative rates, etc.

Engineering data will include sampling of the status and performance of individual components and subsystems. Certain of these data will be available to the operator for monitoring purposes (fuel remaining, V, etc.) while others will be recorded primarily for the post-flight evaluation.

The primary data to be collected in the flight evaluations involve the performance measures. These measures will include quantitative indications of performance accuracies, times (to respond and to perform), and energy expenditures (fuel, power, force applications and operator workload), as well as qualitative information derived from operator comments and opinions.

The FFTO in-flight evaluation is not readily amenable to the application of the scientific method wherein the experimental design provides for rigid control of conditions and the data acquired are appropriate for statistical analysis and prediction. This follows from the fact that, while the missions are intended to provide for an evaluation of system performance, they are also constituents of the operational missions of the Shuttle. The experimental design to be implemented in the evaluation exercises will be such to ensure a high degree of data reliability (repeatability of data—a function of experimental control) and data validity (relevance of data—a function of fidelity of experimental conditions).

Following initial in-flight experiments in 1979 or 1980, it is anticipated that one free-flying teleoperator mission per year will be required using a portion of the Sortie module for the control station and a portion of the pallet to deploy and dock the free-flying teleoperator spacecraft. The Sortie mode provides low-cost opportunities to evaluate advanced teleoperator subsystem technology and to resolve any man-machine problems that may occur in the space environment in a manner responsive to the needs of near-term and long-term manned space missions.

APPENDIX E

ESRO CONTRIBUTION

CHAIRMAN'S NOTE

As Panel Chairman, I wish to take the prerogative of including the following European Space Research Organization (ESRO) material as submitted.

Professor Lindop has done an excellent job of collating a rather diffuse amount of information into a clear and concise representation of the status of the ESRO effort at the time the document was prepared. Much of Professor Lindop's professional contribution is included throughout Appendix A, SPACE BIOLOGY, with special emphasis in Radiation Biology. There is no doubt that the ESRO/ Life Sciences meeting held in Frascati, Italy in mid-January will produce a more extensive representation of the European Life Sciences community. However, the written results of the January, 1973 ESRO/Life Sciences meeting are not available in time to be included in this report. Therefore, I have elected to include the following report to insure that, at least, a preliminary reflection of the ESRO participation is included.

PROPOSALS FOR SPACE SHUTTLE APPROX. 1975, 1976

ORGANIZATION

Proposed in April 1972.

The PALIS (Post Apollo Life Sciences) Working Group, convened by ESRO is coordinated by Mme. A. Lemarchand (Assistant Admin. Director: J. ORTNER). It comprises individual Europeans, but not their laboratories. Advertisements about the possibilities for European laboratories taking part should be in journals such as Nature. A preliminary inventory of European laboratories already or about to become involved should be considered.

OBJECTIVES

The objectives, under Monroy's chairmanship, should be to:

- Define a framework for a European Life Sciences programme;

- Assess, within or outside its own programme, spontaneous project proposals, and, as needed, initiate new proposals.

In addition the Group will have a link from ESRO to the joint NASA/ESRO users group mentioned in the report CSE/CS(72)6.

ESRO/PALIS DISCUSSIONS (PRIOR TO DECEMBER 1972)

General Introduction

During the last few years, the efforts of the United States have resulted in a tremendous development of space technology, not the least of which is exemplified by the Apollo programme which brought man to the moon. These efforts have posed questions to biologists and medical people throughout the world. These questions are related to the effects seen in astronauts during and after space missions and are preliminarily adduced to the effects of weightlessness in the space environment and possibly of cosmic irradiation. The challenge for the biomedical research community is that an approach to understand these effects would go beyond the improvement of man's survival in space and into the mechanisms by which weightlessness influences and affects basic biomedical reactions. This understanding of the mechanisms involved in the adaptation of mammalian organisms to space flight conditions will ultimately depend on an understanding of the basic molecular biological interactions involved. Europe has developed a unique expertise in this field of biomedical research, particularly in the field of molecular biology. Further, Europe has maintained the mechanistic approach to the patho-physiology of interactions of the mammalian organisms in changing environmental conditions. It is, therefore, proposed that the European scientific community participate in the further development of the biomedical space research programme and utilize the technological advances made by the US in previous years.

These developments offer Europe a unique opportunity to participate in augmenting profitable research areas without duplicating the investment costs of the technological development. If the European scientific community is not given this opportunity to participate important scientific developments will be proceeding from which the European community will inevitably be divorced and to which the European expertise cannot contribute.

Rationale of Biological Programme

The proposal is to consider the variables of radiation, lack of rhythm (each accessible to ground experimentation) and weightlessness. The unique situations prevailing in space vehicles are the zero "g" condition, its combination with the absence of externally imposed rhythms, and the additional qualities of ionizing and other radiations. Space flights offer an environment in which to investigate the role of gravity, rhythms, and radiations in biological processes, questions pertinent to both fundamental biology and medicine. Both the one "g" condition and rhythms (and possibly radiation) are two of the basic parameters under which life has evolved on our planet.

Two possibilities may be considered: either that their absence would upset some of the essential life processes, or, that so far these parameters are irrelevant at the molecular level, while being important at higher levels of organization. At which level of organization do weightlessness and/or rhythms become important for biological functions? Indeed, should, for example, the one "g" condition prove to be important for the enzyme-substrate interactions or for the effector-induced conformational changes of allosteric proteins, this would have tremendous implications not only for our understanding of the basic mechanisms of the functioning of biological molecules but also for the evaluation of the effects of zero "g" conditions on organisms. However, it appears highly unlikely that absence of gravity may affect individual reactions in solution to any significant level. On the other hand, processes like ionic diffusion, which may play a significant role in the establishment of gradients, are more likely to be influenced by gravity. Experiments on this subject may have great biological relevance.

Biological rhythms are, according to our present state of knowledge, expected to play an insignificant role at the molecular level, whilst they may become decisive factors as the highest levels of biological organization are considered; that of populations be they of cells or of organisms. Is rhythmic dependence inherent to individual cells or does it influence cell populations and the more complex level of the organism?

Particular mechanisms need to be explored at the following levels:

- Subcellular - particularly the intracellular reorientation of subcellular particles.
- The cell, both as an envelope (membrane) maintaining isolation and as a reproductive unit.
- Organisms, particularly those with gravity oriented evolution, especially in the nervous system.
- Populations of organisms.

One or more of the following different levels of organization may need to be used to clarify a particular mechanism:

- Ecosystems - on populations of man and small mammals; on populations of insects, algae and micro-organisms.
- Organisms - fertilization to maturation and differentiation.
- Cellular - single cell, intracellular and intercellular effects.
- Isolated biomolecular and subcellular particles.

Priority should be given to the unique condition of weightlessness as a tool. This could be facilitated by also studying its interaction with radiation and absence of biological rhythms to potentiate the mechanisms of weightless alone radiation or absence of rhythm. Of particular relevance is the role of the mammalian cell membrane damage if it interrupts the feedback mechanisms to the nucleus and isolates the cell from signals of adjacent cells.

Some specific examples of proposals are given below.

Specific Examples

Miniature Ecosystems in Space Vehicles. (Professor G. Basei, Zoological Station, Naples)

The study of microsystems inside space vehicles could significantly contribute to the solution of the dynamic interaction of the forces involved in promoting given photo-synethic and respiratory rates. Miniature ecosystems containing a limited number of species can be studied easily. Serious problems may arise from restricted feedback mechanisms at the different levels of the food chain. Contrasting difficulties would be raised in the case of microecosystems containing a high number of species. The autonomy and survival of such systems will also be conditioned by a number of abiotic environmental factors such as: the size of the ecosystems, the duration of the experiments, intensity and composition of light, periodicity, temperature, agitation, gravity, etc. Decisions in favour of a completely artificial ecosystem or of natural ecosystems should be taken on the basis of such abiotic factors and of the possibility of varying some of them during the course of the experiments.

Artificial Ecosystems—A model of artificial ecosystem may be conceived as monospecific or multispecific at the levels of producers and of primary consumers, which may either be unicellular or multicellular or both. The level of reducers will be multispecific in any case in order to ensure the availability of all kinds of mineralizing bacteria. The introduction of inbred strains should be avoided in order to maintain the largest possible store of genetic information.

Monospecific composition at the producers and consumers levels should give clearer results but on the other hand it would raise problems of regulation. The introduction of two or three species at each level will, on the contrary, raise problems of competition which might, in turn, be influenced by experimentally induced environmental variability. Either motile or non-motile unicellular algae, or both, should be employed in the system according to conditions. The food chain would thus be the following:

1. Unicellular algae (1 or 2 species motile or non-motile or both)

2. Consumers (1 or 2 species, unicellular or multicellular or both)

3. Mineralizing bacteria.

Natural ecosystems—Natural ecosystems could also be employed. One of the main advantages in favour of such a choice would consist in the existence of a net of ecological niches which has already been established by natural selection in the sea, in lakes, or in ponds. The complication of such a net will on the other hand, inhibit a clear cut analysis and interpretation of the dynamics of the ecosystem and of the changes induced by environmental variables.

Cell Division, Differentiation and Morphogenesis

A second series of experiments (related to some of those proposed by Mayheux et al) may be conducted concerning cell division, differentiation and morphogenesis; enclosed is a group covering such a range, which Lima-de-Faria had collected from the Palis Group.

Biological Phenomena	Organisms or Cell Systems to be Used	Laboratory
1. Fertilization	a. Sea urchins	Zoological Station Naples
	b. Frogs	Dept. of Zoology, Oxford (J. Gordon)
	c. Mouse	Inst. Animal Genetics, Edinburgh (A. McLaren)

2. Birth	a. Sea urchins	As above
	b. Frogs	" "
	c. Mouse (Fetal life = 20 days DNA synthesis = 10 - 13 days)	" "
3. Cell Differentiation		
i. Amplification	a. Xenopus	Inst. Animal Genetics, Edinburgh (M. Birnstiel)
	b. Acheta (Cricket) (40 days from egg to oocyte differentiation)	Inst. Molecular Cytogen., Lund (A. Lima-de-Feria)
ii. Fusion of Mouse Embroyos with Different Genetic Markers	a. Mouse	Inst. Animal Genetics, Edinburgh (A. McLaren)
4. Rates of Cell Division	a. Tetrohymena (Cell synchrony)	Carlsberg Biologist Inst. Copenhagen (E. Zeuthen)
	b. Human lymphocytes stimulated with phytohemagglutinin	Folkhälsans Inst. of Genetics, Helsinki (A. De La Chapelle)
	c. Ascytes Tumours	Inst. of Genetics, Univ. of Lund (A. Levan)
5. Biological Clock	a. Sunflower Helianthus	Lund Institute of Technology, Lund (A. Johnsson)

INFORMAL PROPOSALS ARISING FROM NASA PALIS INTERACTION, DECEMBER 1972. Patricia J. Lindop

Medical and Paramedical Areas

In looking through the proposed (and past) biomedical investigations it seems that the European group could contribute particularly to a mechanistic approach rather than the global data collecting programme. For us, it would seem advisable to consider afresh the proposed medical programme, bearing in mind the space/technical limitations, with which all are newly becoming familiar; and realising that some topics must already have been considered and rejected by NASA.

My main hypothesis depends on the following criteria:

1. Phenomenon studied must have quantitated dose response data on earth whether or not the mechanism is known.

2. When a phenomenon has been observed already in space, the mechanism should be the primary aim of any repetitive observations.

3. Since weightlessness is the unique feature, mechanisms proposed should have a theoretically valid dependency on gravity.

4. Interactions of weightlessness with low and high LET radiation, UV, etc., should be investigated.

5. Where possible phenomenon should be tested across several species with the possibility of extrapolation to man.

6. In confines of space Sortie, simulated variables,

   e.g. zero "g" 0.5 g 1.0 g 2.0 g

   e.g. low LET radiation ^{60}Co

   e.g. high LET radiation Cf^{252}

   e.g. closed populations - flora

7. Long term studies should be maintained in statistically sufficient numbers.

8. New experiments should only be designed in the light of available data.

9. No routine data monitoring ("in case" type monitoring) should be involved.

Examples of Experiments in Initial Phase

1. The effect of gravity on cellular orientation and growth
   Purpose: Single clone lines of normal cell origin, will be compared with single clone lines of neoplastic cell origin. Applied value will lin in an understanding of intercellular cohesiveness.

General Methodology:

- Mammalian cell life, e.g. embroyonic lung or Chinese hamster to be grown as monolayer (plated before flight); as monolayer (plated after different times in flight); in suspension - fluid; in agar - semisolid.
- HeLa cell line under conditions as above.

Phenomena:

1. Will mutation rate (scored by karyotyping at different times after exposure) be affected to the same, more or less in normal and malignant cells?

   (Probability that rapidly dividing cell populations since 0 g effects spindle formation will shown higher gross mutation rate; either as chromosome aberrations; or abortive clones).

   This should be controlled at 1 g and 2 g; perhaps on one type of growth medium e.g. suspension.
2. Will clonal formation occur or will myriad individual cell growth occur?

Phase 2:

- Do similar experiments on mouse haemopoietic stem cells; and mouse leukaemia stem cells.
- For functional capacity, life restoration for normal and infectivity, e.g., for leukaemia cells.

Phase 3:

Organ culture.

Requirements:

- Separate controlled incubator facilities, with optimum gas supply
- Try layered plating on Milar tape; to be able to use antibody fluorescent techniques, for alteration of function. Impact of fixation.

  "Clean" conditions - man handling once per day.

2. a. Effect of gravitational field on oxygen carrying capacity and release using mammalian red cells - (relevance to Fe loss?)

Purpose: Mammalian erythrocyte conformation and membrane elasticity is optimum for oxygen uptake and release.

Methodology:

Groups of mammaliam reticulocyte series would be maintained in vitro, ranging from the erythroblast, reticulocyte and erythrocyte. Different sources should be from foetal mammaliam blood; mature mammaliam blood; senescent mammaliam blood. Oxygen carrying capacity and oxygen dissociation curve at different oxygen gradients can be measured at different time intervals 2, 4, 7 days after exposure.

Could also be cf. with nucleated cockerel erythrocytes with different electrophoretic characteristics.

Requirements:

In vitro culture systems as above. A few recipient mice to test the "functional" capacity, as re-colonizing haemopoietic tissue. 2 mothers + litters: No cleaning, water or food replenishment required during 7 days. 1 man handling.

2. (b) Membrane permeability phenomena in relation to Na^+/K^+ imbalance; Ca^+ metabolism

Purpose: To determine whether Na^+/K^+ reversal is reflection of general intracellular leakage.

Endpoint: Peripheral nerve transmission type, with and without synaptic delay using frog-sciatic nerve preparation - or squid.

Requirements:

- Screened electrophysiological cage, and oscilloscope to measure.
- Man required. Approx. 25 frogs or 12 squids. (No attendance needed within 7 days).
- No environmental shut-off needed.

Phase 2:

Ca^{45} tracer studies on mice to study fate of Ca^+. Isotope protection and so two experiments i.e. with cells and isotopes could be carried out together, particularly in comparing growing and adult bone.

Rationale for 2 (a) and 2 (b):

Membrane changes, permanent or temporary, may lead to any of the following effects such as:

- Permeability changes - leading to shifts in intracellular/extracellular ionic ratios, e.g. Na^+ and K^+. Such ionic shifts would be relevant e.g. particularly to the central nervous system, with respect to the blood-brain barrier; to red cell fragility and membrane flexibility, as well as to the red blood cell efficiency for O_2 carriage; to the peripheral nervous system, particularly in relation to impulse conduction rate; and synaptic transmission.

- Permeability changes in the endothelial vessels of the blood vascular and lymphatic systems will effectively be additive to, or multiply the ionic shifts in (i). Thus, two main systems can be directly affected; renal function; and gaseous exchange in the lung alveoli.

The advantage of this approach is that it may help to differentiate between the effects of space conditions due to the haemodynamic fluctuations in space, which may be rapidly reversed on return to the earth environment. Such changes could therefore be accessible to preventive measures in flight; and also are less likely to lead to latent long term damage.

If, however, the membrane changes result from a combination of e.g. oxygenation, weightlessness, and even a rare high LET event in the tissue, there is a serious problem both of their prevention in flight, and of a higher probability of leading to latent irreversible effects.

3. Effect of gravitational fields on respiratory gas exchange and blood pooling on redistribution in lungs of (a) horizontal mammal or with (b) vertical mammal

Endpoints: Functional respiratory sampling. Peripheral blood oxygenation; and HCO_3 base etc. On mammals: Morphological and quantitative studies of pulmonary alveolar and bronchiolar cells; quantity and viscosity of surfaciant. Young mice (lung growth) ef. with mature mice. ^3H thymide then later ^{14}C thymidine to demonstrate possible adaptions of (a) bronchiolar epithelium - rapidly dividing; (b) alveolar epithelium - limited at most to 3 - 5 divisions.

Some data could be made on in vitro labelling of human bronchiolar epithelium (once probably).

- No special environment.

Relevant to man's response to pressurization; hyperoxia; pH imbalance etc. Soviet programme using hypoxia - problems of atelectasis. Combination of pulmonary blood pooling; inclastic corpuscles and vagal inhibition.

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